Weeds

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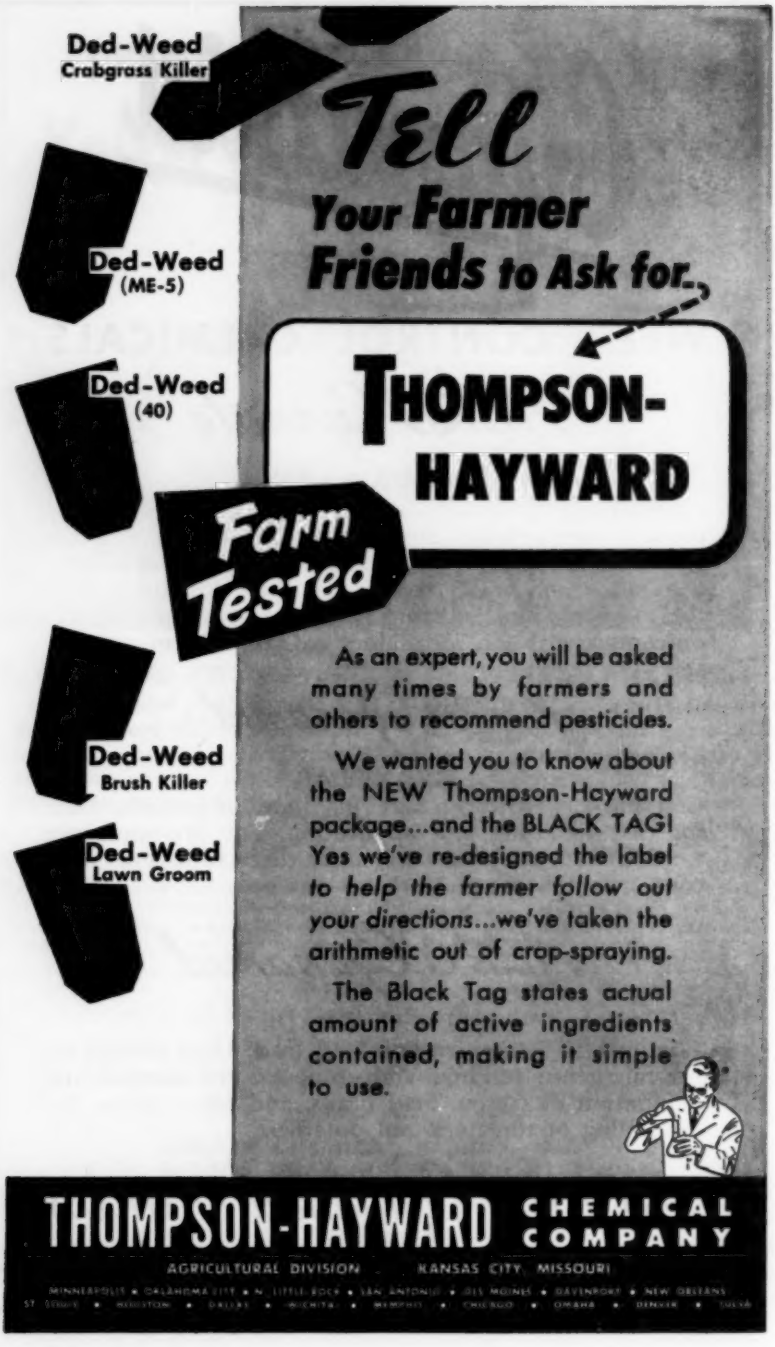
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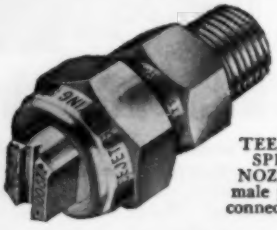

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Terminology

THE QUESTION of uniformity of terminology for the weed control field is beginning to receive the coordinated attention we think it deserves. About ten plant societies, including this one, have been formally contacted by the American Society for Horticultural Science with a general proposal for clarifying the terminology situation. The response to that society's proposal has been most gratifying. Each organization was very much aware of the problem and several had specific suggestions for procedure.

At this writing a possible course of action appears to be developing along the following lines: First, each society is to attempt to put its own house in order and is to have representation on a general committee. The general committee will attempt to resolve differences in terminology between societies. It will also work closely with the national advisory committee already functioning at the national and international levels with problems of terminology, toxicology, etc., in the entomology and pathology fields.

The Association of Regional Weed Control Conferences is studying the problem of terminology and gave it considerable attention at the meeting of its officials in Washington, D. C. in early May. Presumably each of the four member conferences will have representation on a committee. Then, through this committee, there will be representation on the general committee mentioned earlier.

Progress undoubtedly will be slow, but recognizing the problem and planning a general course of action usually is better than half the battle.

Weeds

JOURNAL OF THE ASSOCIATION OF REGIONAL WEED CONTROL CONFERENCES.

VOLUME I APRIL 1952 NUMBER 3

Inactivation of 2,4–D by Riboflavin in Light[1]

J. R. HANSEN and K. P. BUCHHOLTZ[2]

GALSTON AND BAKER (2) have established that riboflavin is a photoreceptor in the destruction of auxin by visible light by *in vivo* and *in vitro* experiments. Carrol (1) showed that riboflavin also reduced the activity of 2,4–dichlorophenoxyacetic acid (2,4–D). He believed that the reduction in activity occurred only in the presence of living plant material. The present studies using corn seedlings confirm the reduction in 2,4–D toxicity by riboflavin when the seedlings and substrate were illuminated. In addition, the inactivation of 2,4–D by riboflavin by light *in vitro* was also shown.

METHODS

Experiment I. Response of corn seedlings to 2,4–D with illumination of seedlings and their substrate was studied in the first experiment. Four solutions containing 1 percent agar were made up to be used as substrate: (1) agar only, (2) agar with 1 ppm 2,4–D, (3) 0.001 molar riboflavin in agar, and (4) 1 ppm 2,4–D with 0.001 molar riboflavin. From each of the four solutions 15 ml of the media were placed in each of twenty 8-inch test tubes. The tubes were plugged and autoclaved. After the agar had congealed, one surface-sterilized corn seed was placed on the agar in every tube. The tubes were divided into two series containing ten tubes from each of the four substrate mixtures. One set was illuminated with two 100 watt lamps against a white background, and the other was placed in a dark cabinet. Seedlings were allowed to grow for 7 days from the time that germination was initiated. Roots and shoots were weighed and measured for possible growth differences.

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[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wisconsin. Published with approval of the Director of the Wisconsin Agricultural Experiment Station. Part of a thesis submitted by the senior author to the Graduate Faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Supported in part by the Research Committee of the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

[2]Formerly Research Assistant in Agronomy, University of Wisconsin, now Assistant Agronomist, Kentucky Agricultural Experiment Station, Lexington, and Associate Professor of Agronomy, University of Wisconsin.

Experiment II. Possible *in vitro* inactivation of 2,4–D was next investigated. Flasks containing 50 ml of 0, 1, 5, and 10 ppm 2,4–D solutions in all combinations with 0.0, 0.0001, 0.001, and 0.002 molar riboflavin were illuminated with two 100 watt lamps against a white background for 96 hours. A duplicate series was stored in a dark cabinet for the same period of time. After the 96-hour period the solutions were made up to their original volumes, and the liquid was used for germinating corn seeds in a test for residual toxicity. For each treatment, 10 ml of the solution were placed in triplicate 10 cm petri dishes, each containing 15 corn kernels. Seeds were germinated for 72 hours, after which time primary root lengths of the seedlings were measured as a relative index of 2,4–D toxicity.

Experiment III. The possibility that 2,4–D toxicity might be altered by a breakdown product of riboflavin or a breakdown product of riboflavin resulting from illumination with 2,4–D was also considered. Solutions containing 0.002 molar riboflavin with 0, 10, 50, and 100 ppm 2,4–D were illuminated for 96 hours. After illumination, the riboflavin solutions at each of the original 2,4–D concentrations were divided into three aliquots. Additions of 2,4–D were made to two of these aliquots, making an additional concentration of 1 and 5 ppm 2,4–D. No 2,4–D was added to the third. All solutions were diluted so that riboflavin concentration was constant throughout all treatments. Corn germination was used to test toxicity of the final additions of 2,4–D, comparing these to standard solutions of 2,4–D in distilled water.

In supplementary studies one of the breakdown products, a phenol, was tentatively identified by its reaction with bromine.

The sodium salt of 2,4–D was used in all experiments reported here.

RESULTS

Data presented in Table 1 indicate growth of seedlings in Experiment I. In non-illuminated cultures containing 2,4–D the addition of riboflavin caused a minor improvement in root growth but gave no evidence of improving top growth. In cultures without 2,4–D

Table 1. Growth of corn seedlings after one week on agar media containing 2,4–D and riboflavin.

Riboflavin concentration	2,4-D concentration			
	0 ppm		1.0 ppm	
	Root length cm.	Top length cm.	Root length cm.	Top length cm.
	Not illuminated			
0	13.1 ± 1.4†	12.7	2.2 ± 0.3	8.9
0.001 M	16.0 ± 1.4	13.3	3.0 ± 0.3	7.4
	Illuminated			
0	12.2 ± 0.9	12.2	1.3 ± 0.1	7.1
0.001 M	16.4 ± 0.7	12.4	4.9 ± 0.3	10.6

†Standard error of the mean.

root growth was increased noticeably by the riboflavin addition. In illuminated cultures containing 2,4–D both top and root growth of corn seedlings were increased markedly by the addition of riboflavin. As before root growth was increased by riboflavin when 2,4–D was omitted.

The results of Experiment II, Table 2, show that toxicity of 2,4–D solutions was effectively reduced or eliminated during exposure to light. The presence of riboflavin did not alter toxicity of 2,4–D in solutions stored in darkness, and illuminated riboflavin solutions containing no 2,4–D did not increase growth. However, all illuminated riboflavin solutions that had contained 2,4–D allowed normal root growth. This demonstrates apparent photochemical inactivation not involving plant tissues. The light and dark treatments were applied to solutions only, then a germination test for residual toxicity was carried out in darkness.

Table 2. Root length of corn seedlings germinated in 2,4–D solutions that were illuminated or stored in darkness for 96 hours prior to germination test.

Riboflavin molar conc.	2,4-D ppm	Root length, cm.	
		Solutions illuminated	Solutions stored in darkness
0	0	4.12	4.99
0	1	2.51	3.06
0	5	1.77	1.79
0	10	1.44	1.52
0.0001	0	4.50	5.21
0.0001	1	5.01	3.07
0.0001	5	4.50	1.86
0.0001	10	4.49	1.49
0.0010	0	4.11	5.24
0.0010	1	5.19	3.17
0.0010	5	5.65	1.83
0.0010	10	5.52	1.43
0.0020	0	5.10	4.91
0.0020	1	4.43	3.09
0.0020	5	4.71	1.79
0.0020	10	4.42	1.61

The possibility that 2,4–D toxicity was reduced by a breakdown product of riboflavin or a breakdown product of riboflavin resulting from illumination with 2,4–D was considered in Experiment III. Data in Table 3 illustrates that illuminated solutions of 0.002 molar

Table 3. Root length of corn seedlings indicating toxicity of 2,4–D additions to previously illuminated solutions of riboflavin and 2,4–D.

Original solution	2,4-D addition in ppm		
	0	1	5
	Root length in cm.		
0.002 M riboflavin 0 ppm 2,4-D	5.30	2.41	1.95
0.002 M riboflavin 10 ppm 2,4-D	4.09	3.14	1.78
0.002 M riboflavin 50 ppm 2,4-D	4.53	2.80	1.57
0.002 M riboflavin 100 ppm 2,4-D	3.58	2.91	1.62
Distilled water standard solutions	4.01	2.40	1.59

riboflavin that originally contained 0, 10, 50, or 100 ppm 2,4–D were not toxic to corn seedlings, but additional amounts of 2,4–D placed in these solutions caused root inhibition of corn seedlings similar to that of equal concentrations in standard solutions.

The breakdown products of 2,4–D were not positively identified, but a strong phenolic odor escaping from solutions during illumination in the presence of riboflavin suggested the presence of a phenol, probably 2,4–dichlorophenol. This supposition was further substantiated by the fact that a quantitative reaction could be obtained between bromine, substituting at one position in the phenol ring, and a theoretical amount of the 2,4–dichlorophenol calculated from the original 2,4–D. A known excess of bromine was added to solutions, and the unused portion was determined by iodometric titration. Data in Table 4 indicate the speed of the inactivation process where solutions of 0.002 molar riboflavin containing 0.5 mg of 2,4–D per ml (500 ppm) were illuminated under two 40 watt white fluorescent lights. At intervals, an aliquot containing the equivalent of 5 mg of the original 2,4–D material was removed and the amount of inactivated 2,4–D was determined by reaction with bromine. Blanks were run using illuminated riboflavin containing no 2,4–D.

Table 4. 2,4–D breakdown at various time intervals by the action of riboflavin and light.

Time in hours	Residual active 2,4-D in 10 ml.	Method
0	5.00 mg.	Iodometric titration with Br
24	3.96	"
48	2.65	"
144	1.54	"
168	1.42	"
168+	1.32	Corn germination test

Under the conditions in which the data in Table 4 were obtained, the molarity of 2,4–D was approximately 0.0023 while that of riboflavin was 0.0020. Since complete breakdown was not indicated in this case by iodometric titration, the solutions were tested for apparent residual 2,4–D activity by a quantitative corn germination test. Complete breakdown, as indicated by iodometric titration and in experiments summarized in Tables 2 and 3, was obtained when the riboflavin was in a higher molar concentration than the 2,4–D.

Titration of the 2,4–D breakdown product did not appear to be a wholly satisfactory means of chemically assaying the herbicide. It lacks sensitivity at the low concentrations used in most physiological studies, and plant extracts being assayed for 2,4–D content would contain other materials that would react with bromine.

DISCUSSION

The data presented indicate destruction of the 2,4–D molecule in the presence of light and riboflavin. Illumination of seedlings and their substrate containing 2,4–D and riboflavin increased plant growth in comparison to seedlings growing on the same substrate

in darkness. This is in agreement with the work of Carrol (1). Evidence presented from other experiments supports the contention that 2,4–D is inactivated by a combination of riboflavin and light without plant tissues. Illuminated solutions originally containing both 2,4–D and riboflavin failed to inhibit root growth of corn seedlings when seeds were germinated in these solutions in darkness after the illumination period. At the same time, illuminated riboflavin solutions did not stimulate root growth where no 2,4–D had been present, and solutions of the herbicide and riboflavin stored in darkness caused inhibition of growth proportional to 2,4–D concentration. This did not account for the possibility that 2,4–D activity may have been blocked by a product resulting from illumination of riboflavin alone or with 2,4–D. While this contingency was considered, data presented show that illuminated riboflavin solutions, whether they contained 2,4–D before illumination or not, did not reduce toxicity of 2,4–D added after illumination.

The 2,4–D molecule apparently has properties of light sensitivity. Payne and Fults (3) increased the activity of several 2,4–D formulations by exposing them to ultraviolet light. In the work presented here, 2,4–D was inactivated in a process involving visible light. This inactivation amounts to a breakdown or splitting of the active molecule. The role of riboflavin in the breakdown reaction appears to be more than that of a catalyst or activator since it was necessary for the number of riboflavin molecules to equal or exceed those of 2,4–D for complete inactivation. The presence of a phenol was detected after breakdown, and this phenol was tentatively identified as 2,4–dichlorophenol. The side chain of the 2,4–D molecule possibly formed acetate or glycolate.

A similarity in chemical behavior between auxin and 2,4–D is suggested. Inactivation of auxin with riboflavin and light was demonstrated by Galston and Baker (2), and Skoog (5) obtained inactivation of auxin with eosin and white light. Riboflavin in plant tissue may also be important in neutralizing the herbicide, particularly in sunlight. Penfound and Minyard (4) noted more necrosis and greater epinasty in 2,4–D treated water hyacinth and kidney bean plants if shaded as compared to plants in full sunlight. The reaction of 2,4–D and riboflavin in the plant may have further physiological significance.

SUMMARY AND CONCLUSIONS

1. Illumination of seedlings and their substrate containing 2,4–D and riboflavin reduced toxicity of the herbicide.

2. *In vitro* inactivation of 2,4–D was demonstrated by two experiments. Solutions containing 2,4–D and riboflavin were rendered nontoxic to corn seedlings by illumination with visible light. While 2,4–D in contact with riboflavin was completely inactivated by visible light, additions of the herbicide made after illumination exhibited characteristic toxicity.

3. Inactivation of 2,4–D resulted from a breakdown of the herbi-

cide molecule. One of the end products of the reaction was tentatively identified as 2,4–dichlorophenol.

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Seeds of Weedy *Euphorbia* Species and Their Identification[1]

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THE WEEDY annual and perennial members of *Euphorbia* are widespread in the United States, occurring in every state. In at least nineteen states[3] *E. esula* is considered serious enough to be declared noxious by law (PMA, 1946). In other states, to date, the members of this group occupy the position of a minor nuisance, to be controlled in the general clean-up of other weeds. *E. corollata* is noxious in Idaho and Wyoming; *E. lucida* in Idaho and South Dakota.

Several papers dealing with *Euphorbia spp.* have appeared, notably those by Haber (1925), Hanson and Rudd (1933), Barnett and Hanson (1934), Bakke (1936 and 1937), Fix (1946), and Muenscher (1948). In addition these plants have received attention in weed bulletins published by various experiment stations, in recent literature dealing with chemical weed control, and in books dealing with weeds and poisonous plants (Pammel, 1911; Muenscher, 1935, 1939).

The key to the seeds, the illustrations, and the descriptions presented in this paper, may be of help in identifying seeds of *Euphorbia* in crop seeds, or they may be of use in determining the origin of crop seeds. Furthermore, taxonomists, weed control specialists, county agents, and others may find the descriptive material of aid in determining the species of *Euphorbia*.

ECONOMIC IMPORTANCE

Crop Yields

It may be assumed that Euphorbias will have the same depressing effects upon crop yields as do other weeds. Work by Thompson (1927), Merkle and Irwin (1931), and Werner (1933) clearly show the effects of weeds on cultivated crops. Although weedy plots in the above experiments did not necessarily have the lowest average moisture for a given season, they did reach a lower minimum than weed-free plots, indicating that weeds may lower the soil water content at a critical time in the growth and development of the crop plant. Undoubtedly they provide competition for soil nutrients, particularly nitrates.

Fungal Hosts

Weed plants very often act as intermediate or alternate hosts for fungus diseases of cultivated crops. Seymour (1933) lists a large num-

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[3]Arizona, California, Colorado, Idaho, Illinois, Iowa, Kansas, Minnesota, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, Wisconsin and Wyoming.

ber of such instances in Euphorbia, in which, among others, *E. marginata* is affected by twenty-five different molds, rusts, mildews and leaf spots, *E. corollata* by twelve, and *E. maculata* by twenty.

Uses

A few of the species discussed in this paper are often grown as ornamentals. These include Snow-on-the-mountain *(E. marginata)*, Flowering Spurge *(E. corollata)*, Mexican Fire-Plant *(E. heterophylla)*, Cypress Spurge *(E. cyparissias)*, and the Caper Spurge *(E. lathyris)*.

Medicinal properties ascribed to certain species by Stuhr (1933) are not borne out by the "Pharmacopoeia of the United States" (1947), which lists no medicinal properties for any Euphorbia. However, the Cherokee Indians of North Carolina and Georgia (Taylor, 1940) persist in the use of an infusion made of the roots of *E. corollata* and *E. maculata* in the treatment of dysentary, hemorrhages, diarrhea and leucorrhea.

Poisonous Properties

By far the most significant characteristic of the plants under discussion is their toxicity when eaten in overdose, or the dermatitis produced when the sap comes in contact with the skin. These effects are allegedly due to the alkaloid Euphorbon, $C_{29}H_{44}O_7$ isolated from *E. ipecacuanhae* (Pammel, 1911).

Cary, Miller and Johnstone (1924) report that when eaten by stock the plants cause irritation of the mucous membranes of the mouth, stomach, intestines and nose, but rarely result in death.

Blistering of the skin and loss of hair from the ankles of horses working in fields infested with *E. esula* in eastern New York is noted by Muenscher (1939) who notes also that animals will eat the dried plants in hay, but usually avoid eating growing plants.

Chestnut and Wilcox (1901) and Gates (1930) claim that honey produced from plants of *Euphorbia* transmits its toxic properties to the consumer. The former also state that goats feeding on *Euphorbia* will produce poisonous milk.

THE SPECIES AND THEIR SEED CHARACTERISTICS[4]

The taxonomic classification of Wheeler (1941) is used in this paper and the geographic distribution is adapted from Muenscher (1935), Britton and Brown (1931) and Fernald (1950).

E. ammanioides HBK.

Annual; native. Fla. to Texas, including Miss. and La., N. C. and northeastern Va.

Seeds: micro-reticulate, delicately pitted; mottled white; ovoid; 1.6 mm. x 1.2 mm.; line extends half-way around long axis, with hilum part way up this line, rather than at base of seed. Fig. 1.

[4]All illustrations were made by Mrs. M. R. Sheehan, Bailey Hortorium, Ithaca, N. Y.

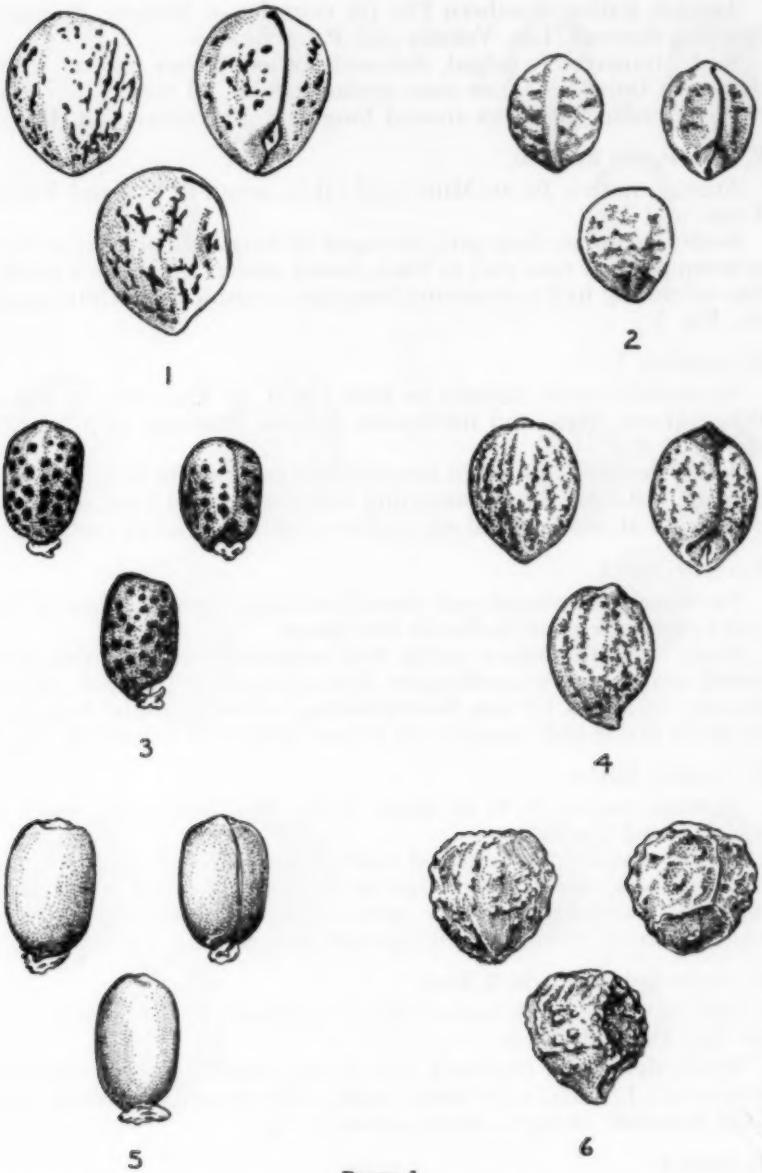

PLATE 1

Fig. 1 — *E. ammanioides* x24
Fig. 2 — *E. buxifolia* x18
Fig. 3 — *E. commutata* x12
Fig. 4 — *E. corollata* x12
Fig. 5 — *E. cyparissias* x12
Fig. 6 — *E. dentata* x12

E. buxifolia Lam.

Annual; native. Southern Fla. (in counties of Monroe, Sarasota, Pinellas, Brevard, Lee, Volusia and Palm Beach).

Seeds: transversely ridged, delicately pitted; silvery gray or white coat with brownish inner coat; globose-ovoid; 1.4 mm. x 1.1 mm.; ridge extending half-way around long axis, line other half. Fig. 2.

E. commutata Engelm.

Annual; native. Pa. to Minn. and Okla., south to Fla. and Texas, Tenn. and Mo.

Seeds: irregular, deep pits, arranged in longitudinal rows of four to seven pits to a row; gray to black; ovoid, terete; 2.4 mm. x 1.3 mm.; line extending half-way around long axis; conspicuous white caruncle. Fig. 3.

E. corollata L.

Perennial; native. Canada to Mass., N. Y. to Fla., west to Texas, Wisc., Minn., Neb. and infrequent in New England. (Up to 4200 feet in N. C.)

Seeds: delicately pitted in longitudinal rows; white to gray; ovoil; 2.5 mm. x 2.0 mm.; line extending half-way around long axis, with depression at one end and nipple-like structure at other end. Fig. 4.

E. cyparissias L.

Perennial; introduced and naturalized from Europe. Mass. to Va. and Colo., infrequent in Pacific Northwest.

Seeds: smooth surface under low magnification, very delicately pitted under high magnification; light gray, some purplish; almost oblong; 2.6 mm. x 1.5 mm. line extending half-way around long axis; flattened at one end, conspicuous yellow caruncle at other end. Fig. 5.

E. dentata Michx.

Annual; native. N. Y. to Minn., S. D., Wyo. and Colo., south to Va., La. and Texas.

Seeds: conspicuous, scattered warty tubercles; dark gray to black; ovoid-globose, somewhat cordate in top view; 2.4 mm. x 2.1 mm.; dark line extending half-way around long axis, slight ridge other half; flattened, cream-colored caruncle part way up the line. Fig. 6.

E. dictyosperma Fisch. & Mey.

Annual or biennial; native. Minn. to Wash., New England south to Ala., La. and Texas.

Seeds: delicately, distinctly reticulated; reddish-brown; ellipsoid, lenticular; 1.5 mm. x 1.0 mm.; slight ridge extending around long axis; flattened, orange-colored caruncle. Fig. 7.

E. esula L.

Perennial; introduced from Europe. New England, N. Y., Maine, Pa., Indiana, Mich., Ill., Iowa, Neb. and Calif.

Seeds: finely pitted; silvery gray, sometimes yellow; ovoid, one end slightly acute; 2.6 mm. x 1.5 mm.; groove extending half-way around

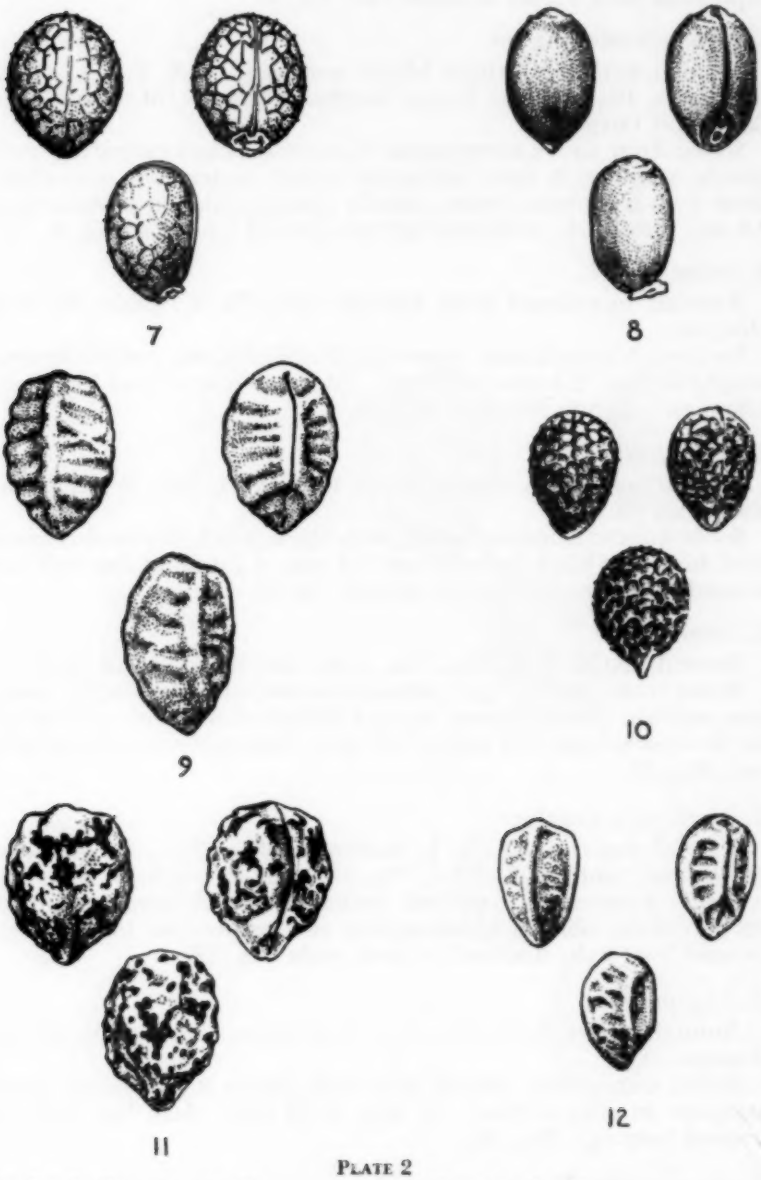

PLATE 2

Fig. 7 — *E. dictyosperma* x20
Fig. 8 — *E. esula* x12
Fig. 9 — *E. glyptosperma* x26
Fig. 10 — *E. helioscopia* x12
Fig. 11 — *E. heterophylla* x12
Fig. 12 — *E. hirta* x30

long axis; yellow-colored, pointed caruncle at one end, slight circular depression with nipple at other end. Fig. 8.

E. glyptosperma Engelm.

Annual; native. Northern Maine southwest to N. Y., Vt., Ohio, Ind., Iowa, Ill., Mo. and Texas. Northwest from N. M. to northern Calif. and Oregon.

Seeds: Four to six conspicuous transverse ridges extending completely across each face, uniformly pitted; outer coat gray-white, inner coat red-brown; ovate, usually quadrangular in cross-section; 0.9 mm. x 0.6 mm.; dark line half-way around long axis. Fig. 9.

E. helioscopia L.

Annual; introduced from Eurasia. Md., N. Y., Ohio, Ill. and Oregon.

Seeds with conspicuous, honey-comb reticulations; reddish-brown; ovoid-elliptical; 2.3 mm. x 1.7 mm.; ridge half-way around long axis; hilum end slightly flattened. Fig. 10.

E. heterophylla L.

Annual; native. Fla. west to Texas, Ill., to S. D., Ind., Wisc., Minn., Kans. and Va.

Seeds: tuberculate-roughened, with black, patch-like eroded areas; dark brown to black; sub-globose; 2.8 mm. x 2.0 mm.; line half-way around long axis, with nipple at end. Fig. 11.

E. hirta L.

Annual; native S. C., Fla., Ala., Ariz., few in N. Y. and Mich.

Seeds: transversely ridged, minutely pitted; outer coat white, inner coat reddish; almost oblong, tapered slightly at one end, quadrangular in cross-section; 0.9 mm. x 0.5 mm.; line half-way around long axis. Fig. 12.

E. humistrata Engelm.

Annual; native. N. Y., N. J., southwest Ohio to Ill., Mo. and eastern Kansas, south to Ala., La., Va., and west to northeast Texas.

Seeds: transversely wrinkled, delicately pitted; brown with silvery overcast; oblong, quadrangular in cross-section; line half-way around long axis; flattened at both ends. Fig. 13.

E. hyssopifolia L.

Annual; native. S. C., Fla., La., west Texas, southern N. M. and Arizona.

Seeds: transversely ridged; gray with silvery flecks; ovoid, quadrangular in cross section; 1.1 mm. x 0.8 mm.; dark line half-way around long axis. Fig. 14.

E. ipecacuanhae L.

Perennial; native. Conn. to Fla., west to Ind., along Atlantic coastal plain and outer Piedmont.

Seeds: irregularly shaped depressions, delicately pitted; outer coat

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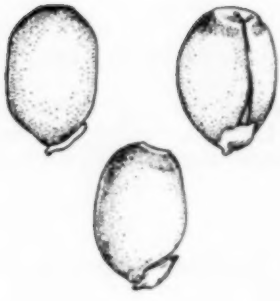

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PLATE 3

Fig. 13 — *E. humistrata* x36
Fig. 14 — *E. hyssopifolia* x24
Fig. 15 — *E. ipecacuanhae* x12
Fig. 16 — *E. lathyris* x8
Fig. 17 — *E. lucida* x12
Fig. 18 — *E. maculata* x24

gray to silver, or yellowish, inner coat layer yellow to brown; oblong-ovoid; 2.8 mm. x 2.0 mm.; groove half-way around long axis, ridge other half; pointed caruncle. Fig. 15.

E. lathyris L.

Annual; introduced from Europe. Conn. south to N. C., west to Ohio, and infrequent in Calif.

Seeds: conspicuous longitudinal wrinkling; light tan, brown or dark brown; oblong-ovoid; 5.0 mm. x 3.8 mm.; dark line half-way around long axis; flattened at both ends; helmet-like caruncle. Fig. 16.

E. lucida Waldst. & Kit.

Perennial; introduced from Europe. Central N. Y., Pa., southern Canada to Iowa.

Seeds: appear smooth to naked eye, finely wrinkled under binocular microscope; gray; ovoid, nearly terete; 2.4 mm. x 1.7 mm.; brown line half-way around long axis; flattened caruncle. Fig. 17.

E. maculata L.

Annual; native. New England and N. Y. south to Texas and Fla., Mich., Wisc., Minn., N. D., Wyo. and Calif.

Seeds: transversely wrinkled, delicately pitted; dull brown to black; obovoid; triangular to quadrangular in cross-section; 1.3 mm. x 1.0 mm.; dark line half-way around long axis, slight ridge other half; hilum end indented, flattened. Fig. 18.

E. marginata Pursh.

Annual; native. Minn. to Colo., Mont. south to Texas, east to Atlantic coast.

Seeds: uniformly tuberculate, delicately pitted; light gray to light brown; ovoid, terete; 3.8 mm. x 2.9 mm.; line half-way around long axis. Fig. 19.

E. obtusata Pursh.

Annual; native. Pa. west to Ohio, Ind., Ill., Iowa, Neb., Kans. and Texas, south to S. C.

Seeds: uniform reticulations, delicately pitted; dark brown to black; orbicular, lenticular; 1.6 mm. x 1.0 mm.; ridge half-way around long axis, line other half; caruncle flat, orange-colored. Fig. 20.

E. peplus L.

Annual; introduced from Europe. New England, western N. Y., N. J., Pa., Md., western Va., Wisc. and Iowa.

Seeds: conspicuous oval depressions, arranged in longitudinal rows of three to six, delicately pitted; light gray, yellow or brown; oblong, nearly terete, quadrangular to six-angled in cross-section; 1.4–1.7 mm. x 0.9 mm.; line half-way around long axis, ridge the other half; caruncle conical, with small nipple set in a depression at opposite end. Fig. 21.

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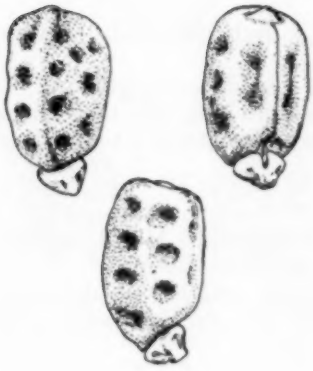

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PLATE 4

Fig. 19 — *E. marginata* x8
Fig. 20 — *E. obtusata* x20
Fig. 21 — *E. peplus* x24
Fig. 22 — *E. platyphylla* x12
Fig. 23 — *E. polygonifolia* x12
Fig. 24 — *E. purpurea* x8

E. platyphylla L.

Annual; introduced from Europe. Canada to Vt., N. Y., Ohio, Mich., Ill., Mo. and shores of the Great Lakes.

Seeds: appear smooth to the naked eye, very delicately pitted under binocular microscope; dark brown, shiny; lenticular, orbicular; 2.2 mm. x 1.7 mm. x 1.2 mm.; line half-way around long axis, ridge the other half; extremely small, pointed caruncle, set in slight depression. Fig. 22.

E. polygonifolia L.

Annual; native. Canada, south to Georgia and along coastal sands to Fla., beaches of Lake Ontario, Erie, Mich., and southern Huron.

Seeds: very delicately pitted; ash-colored; almost lenticular, truncate, slightly cordate; 2.0 mm. x 2.0 mm. x 1.5 mm.; light line on one side. Fig. 23.

E. purpurea Raf.

Perennial; native. N. J. to Ohio, south to Delaware, Md. and western N. C.

Seeds: delicately pitted; shiny brown; ovoid to sub-globose; 4.0 mm. x 3.0 mm. x 2.6 mm.; line half-way around long axis, slight ridge the other half; caruncle flattened, orange-colored; corona-like structure at other end. Fig. 24.

E. serpens HBK.

Annual; native. Canada to Ala., La., Texas and N. M., Ill. to Iowa, S. D., Kans., Mont., New England, N. J., Ga. and Florida.

Seeds: small transverse wrinkles, minutely reticulated, delicately pitted; outer coat white, layer below brown; ovoid; 1.0 mm. x 0.6 mm.; line half-way round long axis. Fig. 25.

E. supina Raf.

Annual; native. Eastern Nova Scotia west to N. D., Wyo., and Texas, Ariz., Oregon, Calif. and South to Fla.

Seeds: very faintly transversely wrinkled, delicately pitted; gray, brown or red with silvery patches; oblong, quadrangular in cross-section; 0.9 mm. x 0.7 mm.; groove half-way around long axis. Fig. 26.

E. vermiculata Raf.

Annual; native. Southern New England, N. Y., Pa., Ohio, N. J., Ind., southern Wisc., Northern Mich., N. M. and Ariz.

Seeds: shallow transverse wrinkles, not extending completely across facets, delicately pitted; dark gray to black, or dark brown, with silvery flecks; ovate, angular in cross-section; 1.0 mm. x 0.6 mm.; line half-way around long axis. Fig. 27.

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PLATE 5

Fig. 25 — *E. serpens* x30
Fig. 26 — *E. supina* x30
Fig. 27 — *E. vermiculata* x20

KEY TO *Euphorbia* SPP. BASED ON SEED CHARACTERS

1. Seeds tuberculate;
   2. Caruncle present; seeds gray, warty in appearance — *E. dentata*
   2. Caruncle absent;
      3. Seeds light colored; tubercles small, uniform. — *E. marginata*
      3. Seeds dark colored; tubercles warty, irregular. — *E. heterophylla*
1. Seeds not tuberculate;
   4. Seeds reticulated;
      5. Caruncle present, prominent;
         6. Ridge extending completely around long axis. — *E. dictyosperma*
         6. Ridge extending half-way around long axis, line other half. — *E. obtusata*
      5. Caruncle lacking or inconspicuous;
         7. Reticulations conspicuously honey-combed. — *E. helioscopia*
         7. Reticulations minute;
            8. Hilum at base of seed. — *E. serpens*
            8. Hilum not at base of seed, but part way up the side. — *E. ammionoides*
   4. Seeds not reticulated;
      9. Surface with ridges or wrinkles,
         10. Ridges longitudinal; caruncle helmet-like. — *E. lathyris*
         10. Ridges transverse;
            11. Caruncle present. — *E. lucida*
            11. Caruncle lacking;
               12. Color of seeds dark;
                  13. Hilum end flattened;
                     14. Coat brown with silvery overcast; seed oblong. — *E. humistrata*
                     14. Coat dull brown, black; seed obovoid, hilum slightly indented. — *E. maculata*
                  13. Hilum end not flattened;
                     15. Coat dark gray, brown with silver patches; seed oblong. — *E. vermiculata*
                     15. Coat brown, red, with silvery flecks; seed ovate — *E. supina*
               12. Color of seeds light,
                  16. Outer and inner coats dull gray. — *E. hyssopifolia*
                  16. Outer coats light gray, inner coat red, brown;
                     17. Seeds not angular in cross-section, globose. — *E. buxifolia*
                     17. Seeds angular in cross-section;
                        18. Four to six conspicuous ridges across each face. — *E. glytosperma*
                        18. Ridges not conspicuous, appearing as wrinkles. — *E. hirta*
      9. Surface lacking ridges and wrinkles;
         19. Circular depressions conspicuous;
            20. Caruncle pointed, opposite end has small cone. — *E. peplus*
            20. Caruncle flat. — *E. commutata*
         19. Circular depressions lacking;
            21. Depressions irregularly shaped; caruncle pointed. — *E. ipecacuanhae*
            21. Depressions lacking;
               22. Caruncle present,
                  23. Caruncle distinctly pointed;
                     24. Seeds lenticular, orbicular; caruncle small, inconspicuous. — *E. platyphylla*
                     24. Seeds obovoid, one end acute — *E. esula*
                  23. Caruncle not pointed,
                     25. Caruncle flattened; seed large (4 mm.) — *E. purpurea*
                     25. Caruncle not flat, but conspicuous. — *E. cyparissias*
               22. Caruncle lacking;
                  26. Seeds flattened, one end truncate, other end acute. — *E. polygonifolia*
                  26. Seeds not flattened, angular in cross-section. — *E. corollata*

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The Effect of Aliphatic Hydrocarbons on the Hypocotyls of Cotton and Soybeans and on the Shoots of Nut grass, Johnson grass and other Weeds by the Directional Spray Technique[1]

O. A. LEONARD[2] and V. C. HARRIS[3]

A HIGH DEGREE of control of annual weeds in cotton by the pre-emergence application of dinitro-secondary-butyl-phenol or its salts has led to appreciable commercial interest (1). Leonard, *et al.* (9) showed that the above chemical was promising for controlling annual weeds in cotton, when applied to the soil as a pre-emergence herbicide, and there have been many reports on the method since that time. It was recognized that this treatment did not control perennial weeds such as nutgrass and Johnson grass, and that some additional treatment would be required to control these weeds. In January 1948, one of the authors had the opportunity to see sugarcane weeds in Puerto Rico controlled by the post-emergence application of fortified oil emulsions, and the procedure was included for study in the 1948 cotton tests. The primary interest of the authors was to find a spray that would control the perennial weeds and which, at the same time, would not be injurious to cotton. It was felt that the annual weeds could be controlled rather well by the pre-emergence treatment. The effect of fortified oils and oil emulsions and unfortified oils on cotton hypocotyls and on grass shoots showed that the fortifying chemicals (dinitro-secondary-butyl-phenol and pentachlorophenol) were quite injurious to cotton hypocotyls, but that some unfortified oils showed considerable promise for selectively weeding cotton.

Because of the urgency for a solution of the cotton weed problem, the Delta Branch Experiment Station, Stoneville, Mississippi began studying the weeding of cotton by post-emergence sprays. Talley (12), (13) spearheaded this research in 1948 and 1949. The procedure and equipment for the application of the oils was developed and the general types of oils for weeding cotton determined. Research on this method at State College, Miss. was confined more to studying the effects of pure hydrocarbons on cotton, soybeans, corn, nutgrass, Johnsongrass and weeds. It was believed that by learning the effect of specific hydrocarbons upon crops and weeds, the properties of an oil might be modified or improved. Part of this study has already

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[3]Agronomist, U. S. Department of Agriculture, Division of Weed Investigation.

The authors are grateful especially to the Standard Oil Development Co., Elizabeth, N. J. and the Phillips Petroleum Co., Bartlesville, Oklahoma for supplying the pure hydrocarbons used in these tests.

been briefly presented in the Third Proceedings of the Southern Weed Conference by the authors (11).

It is well known that the aromatics are important constituents in a weed oil; however, the importance of the aliphatic hydrocarbons is not as well appreciated. The present paper deals with the results from studies on the effect of aliphatic hydrocarbons on the plants that were studied and an attempt will be made to bring out the relationships between chemical structure and molecular weight and to see how these characteristics influenced toxicity. A detailed report on the effect of aromatics as herbicides will be reserved for a later publication.

PROCEDURE

The general procedure for the various experiments to be reported was to grow the cotton, soybeans, nut grass, and Johnson grass separately in half-gallon crocks or in gallon cans that had four holes punched in the sides near the base for drainage. First rock and then sand was placed in the bottoms of the cans and then they were filled with soil. The various crops and weeds were planted and when the spraying was to be done later, the containers were placed alongside of a conveyor belt when it was in use. The speed of the belt was 2.9 miles per hour, air pressure 22 pounds, and the nozzle a 65°, .067 g.p.m. flat-fan type.[4] The rate of application of the hydrocarbons was 2.95 gal. per hour or about equivalent to five gallons per acre, considering that the rows to be sprayed were 40 inches apart and that both sides of each row was sprayed. The tip was mounted so as to give a horizontal fan spray parallel with and one-fourth inch above the surface of the soil. By so doing, it was possible to spray grasses and small weeds without spraying the cotyledons of the cotton and soybeans; actually, the spray was confined largely to a rather narrow band about one-fourth inch wide on the hypocotyls. The less-volatile hydrocarbons crept down the plant parts that were treated, so that a much broader band was finally wet by the spray. The method of application simulated field practice. The species studied were nut grass *(Cyperus rotundus)* and Johnson grass *(Sorghum halepense).*

RESULTS

Experiment 1. Preliminary.

The first experiments were conducted in the field in 1948 using oils having various physical and chemical properties. At that time the authors considered that most of the toxicity in an oil was in the aromatic fraction. Commercial and experimental oils from several sources were received. Some samples were obtained from the Shell Oil Co. that had the following characteristics: (1) ACX 201 — this was a naphtha that had a boiling range of 310–390° F. and an aromatic percentage of 15 per cent. (2) ACX 121 — which was the same as ACX 201, except the aromatics had been removed by solvent extraction to about 3 per cent. (3) ACX 44 — the aromatics in ACX

[4]Trade-name TeeJet 650067.

Table 1. The toxicity of a naphtha and its aliphatic and aromatic parts on the hypocotyls of cotton and the shoots of nut grass and crab grass. Treated twice and the injury recorded 3 weeks after the initial treatment.

Naphtha and fractions	Injury		
	Cotton	Nut grass	Crab grass
ACX 201 (naphtha)	none	severe	dead
ACX 121 (naphtha minus aromatics)	none	moderate	severe
ACX 44 (naphtha minus aliphatics)	moderate	dead	dead

201, that had been removed by solvent extraction and was equal to about 75 per cent aromatics.

In the first experiment, ACX 201 and ACX 121 were compared on the hypocotyls of cotton, soybeans and on the shoots of nut grass and crab grass. Two applications were made, the first when the crop plants were 12 days old and the next when they were 19 days old. ACX 201 produced slight injury on cotton, moderate injury to soybeans, moderate injury to nut grass and killed annual grasses. ACX 121 produced no injury on cotton, moderate injury on soybeans, killed nut grass to the ground, and killed annual grasses. It was clear, therefore, that the aliphatic part of this naphtha possessed a considerable amount of inherent toxicity, which, in this experiment appeared to be equal to the naphtha itself.

A second experiment indicates better than the first experiment, the natural differences in the inherent toxicity of the aromatic and aliphatic constituents of the naphtha. Cotton and nut grass were grown together in crocks. Two spray applications were made, the first when the cotton was 18 days old and the second when the cotton was 25 days old.

The results from table 1 clearly demonstrate that the aromatic fraction was more toxic than the aliphatic fraction. The toxicity of the aliphatic fraction to grass shoots was obvious and indicated a need for a more detailed study of the toxicity of specific hydrocarbons. These studies were conducted and are reported in some of the following experiments.

Experiment 2. Response of cotton, nut grass, and crab grass to certain aliphatic hydrocarbons.

The purpose of this experiment was to explore the herbicidal properties of several types of aliphatic hydrocarbons. A single row of cotton seed was planted across the center of each of several half-gallon crocks in the greenhouse, and the crocks placed outside two weeks later. The purpose of moving the plants out of the greenhouse was to enable the plants to develop a cuticle somewhat similar to field cotton. When treated 18 days after emergence, the cotton plants averaged seven inches in height and had long red hypocotyls. Several nut grass tubers were planted in each crock with the cotton. Grasses (mainly crab grass) that developed in the crocks were from seeds that were naturally present in the soil. The sprayings were repeated 25 days after emergence so that all plants were treated twice.

The results from this experiment are presented in table 2 and some of the significant points are summarized below.

Cotton.

Straight chain paraffins.

No toxicity was evident in this experiment.

Branched chain paraffins.

No toxicity was evident in this experiment.

Cyclo-paraffins.

The cyclo-paraffins tested showed no toxicity to cotton hypocotyls.

Straight chain olefins.

Toxicity to cotton hypocotyls increased as the number of carbon atoms in the molecules increased from six to ten and then decreased. With octene, decene–1, and dodocene–1 some discoloration of the hypocotyls was rapidly produced within one day after spraying.

Branched chain olefins.

The branched chain olefins were less toxic to cotton hypocotyls than were the corresponding straight chains. For example, 2,4,4–trimethylpentene was less toxic than octene. Propylene tetramer and triisobutylene ($C_{12}H_{24}$) were less toxic than dodecene.

Cyclo-olefins.

Injury with 4–methylcyclohexene–1 was about the same as with heptene.

Nutgrass and Crabgrass.

Straight chain paraffins.

Hexane resulted in a rapid and localized burn to the shoots. Injury reached a maximum with decane and dodecane and then decreased.

Branched chain paraffins.

The branch chain 2,2,4–trimethylpentane (C_8H_{18}) was less injurious than n–octane.

Cyclo-paraffins.

The cyclo-paraffins studied produced injury which was similar to that produced with the straight chain paraffins.

Straight chain olefins.

The straight chain olefins resulted in more rapid burning of the shoots than did the paraffins but the final effect was not greatly different.

Branched chain olefins.

The branch chain olefins were generally less injurious than the straight chain olefins.

Cyclo olefins.

Injury produced by the cyclo-olefins and cyclo-paraffins was similar. Larger molecules should be studied.

Droplets of dodecane (applied by a pipette) on cotton blades killed the tissue beneath the droplets in about four days, while similar droplets of hydrotriisobutylene had produced scarcely any visible effect – indicating again the difference in toxicity between straight and branch chain hydrocarbons. This, also, indicates that there is a difference between blade and hypocotyl sensitivity.

Table 2. The effect of some aliphatic hydrocarbons on the hypocotyls of cotton and the shoots of nut grass and crab grass. Treated when 18 and 25 days old. Injury recorded two weeks after the 2nd application.

Hydrocarbon	Injury		
	Cotton	Nut grass	Crab grass
n-Hexane	A	B	B
Hexene-1	A	B	B
Cyclohexane	A	B	B
Cyclohexene	A	B	B
n-Heptane	A	B	B
Heptene-2	B	B	C
Methylcyclohexane	A	B	B
4-Methylcyclohexene-1	B	B	C
n-Octane	A	C	E
Octene (caprylene)	C	C	E
2,2,4-Trimethylpentane	A	A	B
2,4,4-Trimethylpentene-1	B	C	E
n-Decane	A	E	E
Decene-1	D	E	D
n-Dodecane	A	C	D
Dodecene-1	C	E	E
Hydrotriisobutylene	A	C	E
Triisobutylene	A	B	D
Propylene Tetramer	A	D	C
n-Tetradecane	A	A	C (chronic)
Tetradecene-1	A	D	D (chronic)

A—no injury B—slight injury C—moderate injury D—severe injury E—dead

Experiment 3. Effects of four successive applications.

Two Johnson grass rhizomes were planted about two inches deep in soil in one-gallon cans. In another set of one-gallon cans, 10 nut grass tubers were planted per can. Seven days after planting the rhizomes and tubers, Stoneville 2B cotton seed was planted in the cans containing the Johnson grass and Ogden soybeans were planted in the cans containing the nut grass. Two weeks later, the first application of hydrocarbons was made and were again applied at weekly intervals until four applications had been made. The plants were grown in the greenhouse.

A description of the plants at the time of the first treatment is given below.

Cotton – There were about six seedlings per can, each was 4 inches tall, and the plants were succulent.

Soybeans – These were two to three inches tall.
Nut grass – There were about seven shoots per can.
Johnson grass – There were about three shoots per can, 6–10 inches tall.
Crab grass and other weeds were present.

The effect of the hydrocarbons on the crops and weeds two days after spraying is indicated in table 3. The results indicate that there was a regular increase in toxicity as the number of carbon atoms in the molecules increased. Thus the effect of octane was between heptane and decane, and octene between heptene and decene.

Some Johnson grass was "cut" by all of the hydrocarbons containing from seven to 12 carbon atoms in the molecules. As the number of carbon atoms increased from seven to 10, injury to Johnson grass

Table 3. The general effect of several hydrocarbons on crops and weeds 10 days after the first and three days after the second spraying.

Hydrocarbon	Injury to different plants				
	Cotton	Soybeans	Nut grass	Johnson grass	Weeds
n-Hexane	None	Slight	Leaves cut†	None	None
Hexene-1	None	Slight	Leaves cut	None	None
n-Heptane	Slight	Slight	Leaves cut	½ cut	Slight
Heptene-2	Dead	Dead	Leaves cut	½ cut	Dead
n-Octane	Slight	Medium	Burned‡	Most cut	Medium
Octene (caprylene)	Severe	Severe	Burned‡	Most cut	Dead
n-Decane	Medium	Dead	Burned‡	All cut	Dead
Decene-1	Severe	Dead	Burned‡	All cut	Dead
n-Dodecane	None	None	Shoot dead	½ cut	None
Dodecene-1	Slight	Slight	Shoot dead	All cut	Dead
n-Tetradecane	None	None	None	None	None
Tetradecene-1	None	None	Slight	None	None

†The tissues of the shoots at the point of contact with the hydrocarbons and part of the shoots above this point were killed.
‡Shoot burned to ground.

Table 4. The effect of four applications of saturated and unsaturated straight chain paraffin and olefin hydrocarbons upon weeds and crops. Data recorded seven weeks after the first treatment.

	Injury to different plants				
	Cotton	Soybeans	Nut grass	Johnson grass	Weeds
n-Hexane	None	Slight	Leaves cut	Slight	Slight
Hexene-1	None	Slight	Leaves cut	Slight	Slight
n-Heptane	None	Medium	Leaves cut	Few cut	Slight
Heptene-2	Dead	Dead	Leaves cut	Most cut	Dead
n-Octane	None	Medium	Dead†	Most cut	Dead
Octene (Caprylene)	Severe	Dead	Dead	Most cut	Dead
n-Decane	Severe	Dead	Dead	All cut	Dead
Decene-1	Dead	Dead	Dead	All cut	Dead
n-Dodecane	Medium	Severe	Dead	All cut	Dead
Dodecene-1	Dead	Dead	Dead	All cut	Dead
n-Tetradecane	Slight	Slight	Center dead	Stunted	No effect
Tetradecene-1	Slight	Slight	Center dead	Stunted	Slight

†Refers to the shoots that were treated and not the ones that developed later.

increased, but longer molecules resulted in a decrease in injury. There appeared to be some chronic injury with the 14 carbon hydrocarbons (evident by reduced size and distortion of the shoots).

Weeds were controlled well with octane and completely with decane. Dodecane had no influence on the weeds at this time. The olefins had a more pronounced effect on weeds than did the paraffins.

Data seven weeks after the first treatment (four weeks after the last application) are shown in table 4. The pattern brought about by the hydrocarbons on the plants was not greatly different from that already presented. The main difference which developed seemed to be with the 12 and 14 carbon hydrocarbons. Dodecane finally "cut" the Johnson grass and tetradecene finally caused the shoots of Johnson grass to die. Cotton and soybeans were killed with dodecene and soybeans were severely injured with dodecane. Tetradecane produced slight injury to both cotton and soybeans. Spraying with tetradecane and tetradecene resulted in the killing of the centers of the nut grass shoots.

The above data clearly demonstrate an appreciable difference in the tolerance of cotton and soybean hypocotyls and this has been repeatedly demonstrated under both greenhouse and field conditions. The data further indicate that n–octane is the only aliphatic hydrocarbon which did a rather good job in killing weeds and which was, at the same time, relatively noninjurious to cotton and moderately so to soybeans.

Experiment 4. Effects of six successive sprayings.

Chemically delinted Stoneville 2B cotton seed, Ogden soybeans, and nut grass tubers were planted separately in half-gallon glazed crocks in Oktibbeha clay soil. Ten nut grass tubers were planted per crock. All of the plants were grown in the greenhouse throughout this experiment and were more succulent and less cutinized than plants grown out-of-doors. All of the plants were sprayed as in previous experiments, eight days after emergence of the cotton (except the checks) and one week later five-sixths of the plants were retreated, etc. until six separate applications had been made at weekly intervals.

The nut grass shoots were two inches tall when first sprayed; the soybeans were two to three inches tall, and the cotton was two inches tall.

The effect of the hydrocarbons on the plants one day after the first spraying.

The effects of one spraying with the different hydrocarbons on the plants one day after the first spraying are shown in table 5. The effect of the various hydrocarbons upon cotton and soybean hypocotyls was similar at this time. The saturated hydrocarbons had no effect on the hypocotyls, except for a trace of burning with heptane. The unsaturated hydrocarbon, heptene, produced severe burning of the hypocotyls, while with decene the burning was slight. Nut grass shoots were completely "cut" at the point of contact with hexane and hexene, but the leaf tissue below the point of contact was normal. Fewer leaves were "cut" with heptane and heptene than with hexane and hexene, but the leaves were more discolored (olive color

with heptene). The only effect of decane was a slight discoloration, while moderate discoloration was evident with decene. Dodecane showed no effect at this time and dodecene showed slight effect. Tetradecane and tetradecene produced no effect.

The reason for describing the plant reactions to the above herbicides one day after the first treatment is to compare these results with the results that developed after a period of time. The toxicity

Table 5. The effect of some saturated and unsaturated straight chain hydrocarbons on the hypocotyls of cotton and soybeans and the shoots of nut grass. Data recorded one day after spraying.

Hydrocarbon	Injury to cotton hypocotyls	Injury to soybean hypocotyls	Injury to nut grass shoots
n-Hexane	None	None	Leaves cut
Hexene-1	None	None	Leaves cut
n-Heptane	Trace burn	Trace burn	Leaves cut
Heptene-2	Severe burn	Severe burn	Leaves cut
n-Decane	None	None	Slight discoloration
Decene-1	Slight burn	Slight burn	Moderate discoloration
n-Dodecane	None	None	None
Dodecene-1	None	None	Slight discoloration
n-Tetradecane	None	None	None
Tetradecene-1	None	None	None
Check	None	None	None

Table 6. The effect of some saturated and unsaturated straight chain hydrocarbons on the hypocotyls of cotton and soybeans and the shoots of nut grass. Data recorded one week after spraying.

Hydrocarbon	Cotton hypocotyls			Soybean hypocotyls			Nut grass shoots	
	Number*			Number*			Number*	
	Normal	Burn	Dead	Normal	Burn	Dead	Alive	Dead
n-Hexane	8	0	0	6	1	0	12	0
Hexene-1	8	0	0	8	1	0	12	0
n-Heptane	7	1	0	5	5	0	12	0
Heptene-2	0	8	0	0	0	6	12	0
n-Decane	4	4	0	0	6	0	11	10
Decene-1	1	7	0	0	2	6	11	10
n-Dodecane	7	1	0	8	0	0	9	10
Dodecene-1	6	2	0	8	0	0	2	12
n-Tetradecane	8	0	0	8	0	0	12	12
Tetradecene-1	8	0	0	8	0	0	12	0
Check	8	0	0	8	0	0	12	0

*Average number of plants variously affected in each crock.

of hexane was most marked at this time because its speed of action was faster than with the other hydrocarbons on nut grass. With the other hydrocarbons, the rate of burning became progressively slower as the number of carbon atoms in the molecules increased, but the action of the larger molecules continued over a longer period of time, because of the lower rate of evaporation, resulting finally in far more injury. The final injury produced was a balance between inherent toxicity and persistence.

Effect of hydrocarbons on cotton and soybean hypocotyls and the shoots of nut grass one week after the first spraying.

The effect of the hydrocarbons on the plants was quite different

one week after treatment than it was one day after treatment – table 6. Injury to cotton and soybean hypocotyls by decane and decene was quite pronounced. Decene was more injurious than decane, and soybeans were more severely injured than was the cotton. All of the nut grass shoots treated with decane and decene died, while an equal number of new shoots replaced them. Dodecane killed the nut grass shoots and an equal number of new shoots developed; dodecene killed the treated shoots and definitely retarded the development of new shoots. Tetradecane and tetradecene seemed to have no effect on nut grass at this time.

Effect of the hydrocarbons on the plants nine weeks after the first spraying.

The effects of from one to six applications of hydrocarbons nine weeks after the initial treatment (four weeks after the last treatment) are described below. The cumulative effects of retreatment are evident.

Nut grass.

The shoots were quickly burned or "cut" with the six or seven carbon hydrocarbons, but the lower part of the shoots generally recovered. Few tubers were killed by these materials, except by six applications of heptene – table 7. The 10 and 12 carbon hydrocarbons burned the shoots more slowly than the six and seven carbon chains, but the 10 and 12 carbon hydrocarbons crept downward and killed the shoots and many tubers, especially with six applications. The 14 carbon hydrocarbons killed the shoots very slowly; in fact, scarcely any visible effect was evident for several weeks. Tetradecene produced visible injury sooner than tetradecane. The center leaves of the shoots were the first to die, followed later by the death of the entire shoot.

Cotton.

Cotton hypocotyls were at least slightly burned by all of the hydrocarbon tested – table 8. Hexane and hexene produced a small amount of shallow burning that was evident on only a few of the cotton plants. Heptane also produced a slight burn on a few plants; the burning with heptene was rapid and severe and progressively produced more injury to cotton hypocotyls as the number of sprayings increased. None of the cotton survived six applications of heptene.

Injury to cotton plants with decane progressively became more severe as the number of sprayings increased; half of the cotton plants were uninjured with four applications, while with six applications all of the cotton hypocotyls were injured, but two-thirds of these would have grown to maturity. In contrast with decane, the injury produced by decene was severe, even with one application, being about as injurious as occurred with six applications of decane. Decene brought about the death of almost all of the cotton plants that were sprayed more than once. The effect of both decane and decene

Table 7. The effect of spraying nut grass with from one to six applications of hydrocarbons on the number of live and dead nut grass tubers per crock. Data recorded nine weeks after the first application[1] (four weeks after the last application).

Hydrocarbon	Number of sprayings											
	1		2		3		4		5		6	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.
n-Hexane	21	1	18	1	18	1	19	1	15	1	13	1
Hexene-1	21	1	19	1	22	1	16	1	15	1	12	1
n-Heptane	20	1	16	1	13	2	11	1	11	2	9	2
Heptene-2	21	1	17	2	13	1	10	2	8	4	6	5
n-Decane	18	1	12	3	10	3	6	6	5	5	4	6
Decene-1	15	1	12	3	10	3	5	5	5	6	3	8
n-Dodecane	17	2	9	8	9	7	4	8	3	8	1	9
Dodecene-1	16	7	5	6	1	10	1	9	1	9	1	9
n-Tetradecane	21	3	18	6	17	7	11	7	14	6	8	6
Tetradecene-1	20	5	12	5	5	7	6	7	3	8	2	10
Check	26	1	26	1	26	1	26	1	26	1	26	1

[1]10 tubers initially planted in each crock. Pots with more than 10 tubers show formation of new tubers.

Table 8. The effect of one to six sprayings of hydrocarbons on the hypocotyls of cotton, nine weeks after the first application (four weeks after the last application). The data are on the number of cotton plants variously affected in each crock.

Hydrocarbon	Number of sprayings					
	1	2	3	4	5	6
n-Hexane	7A	7A	7A	7A, 1B	6A, 1B	6A, 1B
Hexene-1	6A	7A	8A, 1B	7A, 1B	7A, 1B	7A, 1B
n-Heptane	4A, 2B	4A, 3B	5A, 2B	4A, 2B	5A, 2B	7A, 2B
Heptene-2	7C	4C, 2D, 1E	2C, 5D, 1E	2D, 5E	3D, 3E	9E
n-Decane	4A, 4B	3A, 3B, 1E	5A, 3B	4A, 1D, 3E	1C, 5E	4C, 2E
Decene-1	6C, 1E	1D, 6E	7E	7E	3D, 5E	8E
n-Dodecane	3A, 3B	2A, 1B, 3E	2C, 4E	3C, 4E	1D, 6E	6E
Dodecene-1	3B, 1D, 2E	4C, 3E	2D, 5E	6E	7E	7E
n-Tetradecane	8A	7A	7†	7†	7†	7†
Tetradecene-1	6A, 1E	6A, 1E	5†, 2E	6†, 1E	6†, 2E	5†, 2E
Check	7A	7A	7A	7A	7A	7A

A—no injury B—very slight burn C—moderate burn D—severe burn E—dead
†Plants not killed, but injury was different from the other treatments, in that it was produced below the surface of the soil.

was mainly on the hypocotyl, but some burning occurred at the soil line.

Dodecane appeared to be relatively non-injurious to the cotton plants for several weeks, but injury finally developed. Injury produced with three or four applications of dodecane corresponded to that produced with five or six of decane. Injury appeared to occur first at the ground line and to progress upward, which is in contrast to the previous hydrocarbons mentioned, which occurred first at the point of contact of the spray on the hypocotyls. The effect of dodecene on cotton hypocotyls was more severe than with dodecane and injury developed earlier. In this experiment, injury with dodecene appeared to be about the same as with decene, but injury at the soil level was greater.

Tetradecane seemed to be entirely without effect on the cotton

plants; however, after the cotton plants were pulled up, marked injury to the top of the tap root and hypocotyl base was noted. This injury was evident on cotton plants that had received two or more applications and the injury became more pronounced as the number of applications were increased. Since none of the plants were visibly injured at the termination of the experiment, it is not known whether this injury was important or not; however, it seems probable that this injury would have resulted in reduced yield of cotton with three or more applications. Tetradecene was more severe than tetradecane, in that some cotton plants actually died with one or more applications; however, most of the plants were injured below the soil line, the same as with tetradecane and the actual ultimate importance of the injury is not known. This injury produced by tetradecene appeared to be greater than that produced by tetradecane.

The results of this experiment suggest that unsaturated straight chain hydrocarbons should not be used as herbicides for removing weeds from cotton. The data also strongly suggest that one should guard against repeated applications of the 12 and 14 carbon hydrocarbons, because of the chronic injury that these hydrocarbons produce.

Soybeans.

Soybean hypocotyls were burned with hexane and hexene – table 9. Six applications of hexene produced a severe burn to the hypocotyls while the same number of sprayings with hexane produced slightly less injury and is suggestive, at least, that hexene is more injurious to the hypocotyls than hexane.

Heptane was more injurious to soybean hypocotyls than either hexane or hexene, severe burning being brought about by three or more applications. Injury with heptene was considerably greater than heptane, severe injury or death resulting even with one application.

Soybeans were able to withstand one application of decane with very little injury, but two or more applications resulted in severe injury and many plants died with four or more applications. Decene was much more injurious than decane, the soybeans being unable to withstand even one application. Decene resulted in almost all of the soybeans being killed with all treatments, indicating that soybeans were extremely sensitive to this hydrocarbon.

Dodecane and dodecene appeared to be less injurious to soybeans than decane and decene. The soybeans withstood one application of either of these hydrocarbons with little injury being produced, while with dodecane, three applications resulted in a moderate burn. Injury progressed from the soil line upward, the same as with cotton.

Tetradecane and tetradecene produced injury to the soybeans which was below the surface of the soil, the same as with cotton. The extent of the injury was difficult to determine. The results indicate a very sharp difference in toxicity of tetradecane and tetradecene. None of the soybean plants were killed with tetradecane, while some soybean plants died with one or more applications of tetradecene,

Table 9. The effect of one to six sprayings of hydrocarbons on the hypocotyls of soybeans. Data recorded nine weeks after the first spraying (four weeks after the 6th or last spraying). The data are on the number of soybeans variously affected in each crock.

Hydrocarbon	Number of sprayings					
	1	2	3	4	5	6
n-Hexane	5B	4B	2B, 2C	2B, 2C	4C	5C
Hexene-1	3A, 2B	3B, 2C	2B, 4C	2B, 2C	4C	1C, 5D
n-Heptane	6C	5C	4D	5D	4D	4D, 2E
Heptene-2	2D, 2E	2D, 2E	2D, 3E	1D, 4E	1D, 3E	1D, 4E
n-Decane	4B	4D	4D	2D, 4E	1D, 3E	1D, 3E
Decene-1	5E	1D, 4E	5E	5E	4E	5E
n-Dodecane	4B	4C	4C	2C, 2E	2C, 2E	2C, 2E
Dodecene-1	3B	4D	4D	2D, 3E	2D, 2E	2D, 3E
n-Tetradecane	5†	5†	4†	5†	4†	4†
Tetradecene-1	3†, 1E	2†, 2E	2†, 2E	1†, 3E	5E	5E
Check	5A	5A	5A	5A	5A	5A

A—no injury B—slight burn C—moderate burn D—severe burn E—dead
†Plants not killed, but injury was different from the other treatments, in that it was produced below the surface of the soil.

the number of plants killed increasing as the number of sprayings was increased. None of the soybean plants survived five or more applications of tetradecene.

Experiment 5. Response of annual weeds and crop plants to hydrocarbon sprays.

This test was conducted in a manner similar to the previous test and the data are presented in table 10. The Esso VM & P naphtha was similar to octane in many respects. The boiling range was 250° to 290° F., with the 50 per cent being 261° F., which was almost identical with octane (258° F.).

Annual weeds consisted of crab grass, pigweeds, annual morning glory, ragweed, vetch, wild geranium, clover and Oenothera sp. These weeds were greatly reduced by two or more sprayings with hexane and by one or more sprayings with the VM & P naphtha. The control of annual weeds would likely have been even more complete, had the surface of the soil not settled a little below the level of the rims of the cans, so some of them were missed in the spraying operation. Hexane was relatively ineffective against the Johnson grass shoots, because the shoots were rather thick in comparison to the annual weeds and the hydrocarbons must be persistent enough to penetrate far enough, if killing is to occur. The VM & P naphtha had a higher boiling range than hexane and killed most of the Johnson grass shoots; however, most of the shoots that survived the first treatment, were not killed by subsequent treatments. The shoots that survived the first treatment were the larger shoots and these had time to become still larger beween treatments.

Cotton was injured scarcely any by even six applications of the VM & P naphtha. Soybeans were planted but a poor stand was obtained, so the data on soybeans were sketchy; however, the fact that some soybeans survived six applications of the VM & P naphtha is significant and indicates that soybeans can withstand this naphtha fairly well.

Experiment 6. Age of plant study.

The purpose of presenting the data in table 11, is to show the influence of age on the injury that is produced by hydrocarbons upon cotton and soybean hypocotyls. The plants were grown out-of-doors in gallon cans and treated with Shell Dispersol (boiling range 380–490° F.) which was very low in aromatics. The effect of this product might be expected to produce a plant reaction similar to dodecane (b. p. 421° F.). The plants may have been tougher than the greenhouse plants used in most of the previous tests, since the plants in this test were grown in the open.

The results indicate that young cotton was much more sensitive to Dispersol than older cotton; however, the young and older soybeans were almost equally sensitive, both being considerably less tolerant than was cotton. The data indicate that the control of nut grass in older cotton, would be more feasible with Dispersol, than it would be in young cotton.

Table 10. The effect of one to six sprayings with hexane and Esso VM & P naphtha on the number of annual weeds and Johnson grass shoots per crock, and the effect of these sprays upon cotton hypocotyls. Readings were recorded nine weeks after the first application (four weeks after the last application).

Material	Number of sprayings					
	1	2	3	4	5	6
	Number of weeds per container					
Hexane	15	1	1	2	1	0
VM & P naphtha	2	2	2	2	0	0
Check	10	10	10	10	10	10
	Number of Johnson grass shoots per container					
Hexane	9	7	9	9	5	6
VM & P naphtha	1	2	3	0	0	3
Check	10	10	10	10	10	10
	Number of cotton plants variously injured					
Hexane	7A	7A	7A	7A	7A	7A
VM & P naphtha	7A	7A	8A	7A, 1B	5A, 3B	4A, 3B
Check	8A	8A	8A	8A	8A	8A

A—no injury B—slight injury C—moderate injury D—severe injury E—dead

Table 11. The effect of one to six sprayings with Shell Dispersol on the hypocotyls of one and six weeks old cotton and soybeans and the effect of spraying nut grass shoots on the percentage of tuber kill. Readings recorded nine weeks after the first spraying (4 weeks after the last spraying).

Type of plant	Injury by different numbers of sprayings					
	1	2	3	4	5	6
1 week old cotton	none	none	moderate	severe	severe	dead
6 weeks old cotton	none	none	none	none	none	slight
1 week old soybeans	slight	slight	moderate	dead	dead	dead
6 weeks old soybeans	none	moderate	moderate	dead	dead	dead
Nut grass (tuber kill)	20%	30%	40%	80%	80%	75%

DISCUSSION

The saturated paraffin hydrocarbons showed appreciable toxicity to crops and weeds, with the toxicity varying according to molecular weight and configuration. As a group, these hydrocarbons were much less injurious to cotton and soybean hypocotyls than they were to grass shoots. Soybean hypocotyls were less tolerant than were the cotton hypocotyls to the paraffins. The differences in the effect of the paraffin hydrocarbons upon the cotton and soybean hypocotyls and the shoots of grass, nut grass and small weeds makes selective weeding of cotton and soybeans possible. Although soybeans are much more sensitive than cotton to hydrocarbons, they have been successfully weeded with a naphtha in a field experiment reported by Leonard, Harris, and Edwards (10).

The olefines, in contrast to the paraffines, produced marked injury to cotton and soybean hypocotyls and injury to grass and nut grass was appreciably greater with the olefines than with the paraffines. It is clear, from the results, that the olefines used alone would be too toxic to the crop hypocotyls to be used as selective herbicides in removing grass or nut grass from either cotton or soybeans. Edwards, *et al.* (5) suggest that a cotton weed oil should not contain over 2 per cent olefines and diolefines. Crafts and Reiber (2), and Havis (7), (8) have also noted a greater toxicity of the olefines compared to the paraffins, although Havis considered the differences to be small. The present paper emphasizes that the difference in toxicity of paraffines and olefines varies with different plants and plant parts, and that these differences are important when selective weed control is the objective.

Chemically, the olefines are quite reactive, and one would expect them to react variably, depending upon the types of catylists which are present in different plants. The herbicidal properties of olefines seem to fit the chemical consideration; however, the data are explainable on the bases of greater solubility of the olefines in cell membranes than similar paraffines. Currier (3) discussed the merits of the physical and chemical theories on the nature of the toxicity of hydrocarbons, and reviewed the literature.

The branch chain paraffines and olefines were less injurious than the straight chain isomers, but the differences were not great. The straight chains may be able to penetrate the cuticle better than branched chains. Such a theory serves as a logical explanation for the greater toxicity of the straight chain molecules; however, carbon atoms having a tertiary hydrogen are readily oxidized and one should anticipate that these might be slowly oxidized and give chronic injury that is slow in developing.

There was almost no difference in the toxicity of hexane and hexene in these tests. Both of these hydrocarbons produced a rapid and localized burn to grass blades. It is considered that no difference in toxicity was apparent because both compounds evaporated quite rapidly, allowing the olefine, hexene, insufficient time to produce appreciable chemical injury. On the other hand, Currier (4) found

that hexene vapors were no more toxic than those of hexane. It seems doubtful whether hexene is different from the other olefines with respect to producing injury to plants. It seems evident that there is some basic difference in the effect of the liquid and gaseous states of hydrocarbons on plants.

Although the cyclo-hydrocarbons studied in this paper produced no more injury to the plants studied than the straight chain hydrocarbons, it is considered that these results were due to the low boiling point of the compounds that were studied. Porter and Holstun (14) found that injury to cotton plants with oil sprays was influenced somewhat by the naphthene content of the oils used.

With the seven to 14 carbon hydrocarbons, injury with the olefines was appreciably greater than with the paraffines on the grasses and greatly more toxic on the cotton and soybean hypocotyls. The marked differential in toxicity of the paraffines to cotton and soybean hypocotyls and to grass shoots makes selective weed control possible; with the olefines, this differential does not exist, and hence these compounds are unsuited for selective weed control in cotton and soybeans.

There was a relationship between the number of carbon atoms in the molecules and the rate at which injury was produced. The time necessary to produce death of the tissue treated, increased as the number of carbon atoms in the molecules increased. Injury by the olefines was more rapid than with the paraffines. Injury produced by the 14 carbon atom chains was so slow, that the injury was considered to be chronic. It is possible that part of the injury that eventually occurs on plants treated with the heavier hydrocarbons results from the fact that they may be changed into new and more toxic compounds. One advantage of the lighter hydrocarbons in selective weeding, is that they will not be so persistent in the tissues of the crop plants and produce delayed injury. On the other hand, the persistence of the hydrocarbon is an advantage, especially in controlling of some kinds of weeds, such as nut grass. The heavier hydrocarbons evaporate slowly and have time to creep down the nut grass shoots beneath the soil surface and into the tubers and has resulted in a high percentage of the tubers being killed in some tests. Crafts and Reiber (2) found that the unsulfonated residues of stove oil and of heavy isoparaffin that had been stored for several months in light, became very toxic to flax and barley. It seems only logical that similar changes might take place in oils on plants.

It is of interest to note that the boiling point of decane (345° F.) falls near the 50 per cent point of naphthas that are used for weeding cotton, and that octane falls somewhat below the lower initial distillation point of these naphthas. It seems likely that these naphthas consist largely of straight and branch chain paraffins containing a high percentage of molecules with 10 carbon atoms. It is likely that the paraffin fraction of the naphthas is not as toxic as decane, because of the occurrence of branch chain molecules; however, this fraction is effective as a herbicide, as was shown in Experiment 1. Octane, also, was an effective herbicide, although its boiling point

was somewhat below that of the lower part of the naphtha range (258° F.). The VM & P naphtha (boiling range 250–290° F.) was, also, an effective selective herbicide for removing small annual weeds from cotton and soybeans. One advantage of the eight and 10 carbon hydrocarbons in selective weeding is that the injury produced is largely of the acute type. Hydrocarbons containing 12 carbon atoms evaporate more slowly and produce delayed injury to both cotton and soybeans, which makes them less suitable for selective weeding than the eight to 10 carbon hydrocarbons.

The effect of repeated spraying is an important factor in determining the type of hydrocarbons that can be used and represents a somewhat new aspect of selective weeding with oil. The method is now used commercially in cotton weeding in the Southern States. Injury to cotton hypocotyls increased as the number of sprayings increased from one to six. The most likely hydrocarbons for repeated use in weeding cotton were octane and decane. One-half of the cotton treated four times with decane appeared to be uninjured by the sprayings; often this loss in number of cotton plants would not be serious under field conditions. Although four applications of decane reduced the number of nut grass tubers by only 40 per cent, the weight of the shoots nine weeks after the initial spraying was reduced by about 80 per cent. Under field conditions, nut grass is retarded as the cotton plants become larger and this operates as a factor that is in addition to that studied in this paper. Nut grass was quite effectively controlled by five or six applications of dodecane — 90 per cent of the tubers being killed. If the nut grass were controlled for the remainder of the growing season by crop competition, it is conceivable that by repeating the above treatment, one could eventually eradicate nut grass. Unfortunately, most of the cotton was killed by five applications of dodecane. Larger cotton, as shown in Experiment 6, can withstand the dodecane-like hydrocarbons better than small cotton. It might be best to use an octane-like naphtha for the first three or four sprayings and to then use the dodecane-like hydrocarbons for killing nut grass tubers.

The effect of any hydrocarbon on the cotton will vary with the age of the plants and conditions under which it is grown. Harvey (6) has indications, at least, that California cotton can withstand "hotter" oils than Mississippi cotton. Nevertheless, a hazard in repeatedly using heavier oils, is indicated. Leonard and Harris (11) found that 25 per cent trimethylbenzene in Shell Dispersol (boiling range 380–490° F.) was somewhat more effective than Dispersol alone in killing of nut grass tubers and was no more injurious to either young or old cotton hypocotyls. Evidently, the addition of a suitable aromatic would reduce the number of sprayings that would be required to achieve a certain tuber kill.

One or two applications of a hydrocarbon may control annual weeds, if the treatments are applied while the weeds are small. Since only one or two applications may be necessary for annual weed control, it is of less importance to consider what paraffin to use, so long as the sprays are effective on the annual weeds.

Weed control with oils has proven to be more difficult in soybeans than in cotton. Nevertheless, Leonard, Harris and Edwards (10) successfully weeded soybeans. The first spray using 2½ gallons of the naphtha LHH–1 per acre killed most of the small crabgrass seedlings and the second spray at five gallons per acre reduced Johnson grass shoots at harvest time by 90 per cent. Since soybean hypocotyls are so sensitive to the hydrocarbons, it is important to consider what hydrocarbons that can most safely be used. The results from experiment 3 suggest that octane would be a satisfactory herbicide for weeding soybeans, since the soybeans were able to withstand four applications of octane with only moderate injury. In this connection, the VM & P naphtha, whose boiling range was 250–290° F. indicates that it was somewhat similar to octane, was successfully used as a selective for weeding soybeans. Since hydrocarbons having the boiling range of octane evaporate rapidly and therefore have less opportunity to produce injury that occurs by creeping, it is important to spray the weeds when they are very small, if the best control of weeds is to be achieved. It is of interest to note that even hexane is an effective herbicide against annual weeds, if the weeds are very small when sprayed and if the sprayings are repeated a number of times (Experiment 5).

The above indicates that soybeans can be weeded successfully and safely with hydrocarbons, if mixtures are used that contain the lower boiling paraffines (preferably octane) and if the weeds are sprayed when they are still very small. Young and old soybeans are about equally sensitive to hydrocarbons, so there is little advantage in delaying the spraying. In order to reduce the chances of injury, it is suggested that the amount of spray applied per acre be reduced to 2½ gallons with the first application.

SUMMARY

1. Olefines were somewhat more injurious to grass and nut grass than were the paraffines and injury was produced more rapidly.

2. Olefines were very injurious to the hypocotyls of cotton and soybeans, whereas the paraffines were much less injurious.

3. Branch chain olefines and paraffines were slightly less toxic than similar straight chain isomers.

4. The speed at which injury was produced decreased as the length of the carbon chains increased from six to 14 carbon atoms. On small annual weeds where persistence and creeping of the hydrocarbon is less a factor in killing the seedlings, the lower boiling hydrocarbons were satisfactory herbicides. When creeping is an important factor in achieving kill, such as on nut grass, the longer chain hydrocarbons were more effective. However, since the inherent toxicity of the hydrocarbons decreased as the number of carbon atoms increased, tetradecane was less effective than dodecane as a nut grass herbicide.

5. Soybean hypocotyls were more sensitive to hydrocarbons than were cotton hypocotyls.

6. The results suggested that cotton could withstand several appli-

cations of decane. Decane is probably a more effective herbicide than octane, especially when the weeds are tough and when some perennial grasses are present.

7. Octane appeared to be a safer herbicide for soybeans than decane, but to be effective, the weeds would have to be treated while they were still quite small.

8. Nut grass shoots sprayed five times with dodecane showed a 90 per cent reduction in the number of live tubers.

9. The most effective hydrocarbons against Johnson grass were those that contained 10 to 12 carbon atoms.

10. Injury with tetradecane and tetradecene was very slow in developing. Both cotton and soybeans showed injury with these compounds that was apparent beneath the surface of the soil. Johnson grass, nut grass, and crab grass showed chronic injury with these materials.

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Studies on Spray Retention by Leaves of Different Plants[1]

W. B. Ennis, Jr.,[2] Ralph E. Williamson,[3] and K. P. Dorschner[4]

The employment of selective herbicidal sprays to kill or inhibit one or more undesirable plant species growing in close association with desirable species has become a common practice in producing certain crop and pasture species. Many crop and weed plants which are equally inhibited if exposed to certain herbicides during the germination period may show marked differential response when the tops of the same plants are sprayed with the materials. For example, the common small grains and corn are readily inhibited by the herbicide 2,4–dichlorophenoxyacetic acid (2,4–D) if exposed to solutions of the herbicide at the germination stage. Notwithstanding, 2,4–D is widely used in spraying these crop plants at certain stages to control weeds without causing significant damage to the crops. The lack of serious damage to these species from applications of 2,4–D to their tops may be attributed to several factors. Firstly, the spray may be repelled and shed harmlessly to the soil by the crop species and retained by the weedy ones. Secondly, the spray may be retained about equally well by the foliage of all species, but absorption and translocation of the herbicide to susceptible tissues, such as the stem and root apical meristems, may be less efficient in the non-susceptible species than in the susceptible ones. Possible differential accumulation of herbicides at the site of toxic action by susceptible and tolerant plants also may be important. Thirdly, the differential response of plant species to certain herbicidal sprays may be attributable to an inherent physiological capacity of the non-susceptible plant to tolerate the herbicide even in intimate association with the cellular components. Fourthly, some herbicidal materials appear to be readily taken up by the normal absorbing organ, the roots, of plants, but are not absorbed efficiently by the aerial plant parts because of certain physio-chemical relationships and internal morphological barriers. Fifthly, the position of the stem growing point may be a factor influencing the differential response of plants to herbicidal sprays. The apical bud of the stem in most broadleaf plants is usually wet by foliage sprays, whereas the stem bud of grasses is protected by several enveloping leaves. Sixthly, some species may inactivate the herbicide more rapidly than others and hence are not highly responsive.

This paper is concerned with studies on certain of the factors relating to the selectivity of foliage sprays of certain herbicidal materials.

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REVIEW OF LITERATURE

Several workers have described factors influencing the effectiveness of plant growth-regulating sprays. Smith (1946) found that large droplet sprays applied at low pressure were retained by soybean plants to a greater degree than small droplet sprays applied at higher pressure. Fogg (1947) found large differences between species in the extent to which the leaves are wetted by water and suggested there may be variation in wettability between different leaves on the same stem of some species. Ennis and Boyd (1946) found that the addition of Carbowax to aqueous solutions of 2,4–D enhanced the inhibitory effect of the substance when applied to Red Kidney bean plants, but the Carbowax did not increase the inhibitory effectiveness over wholly aqueous spray on soybeans. These workers suggested that the dissimilarity in the response of the two species to the Carbowax and wholly aqueous sprays might be related to the difference in leaf pubescence. It has been demonstrated that the addition of a hygroscopic agent increases the total amount of toxicant passing into leaves (Hopp and Linder, 1946; Rice, 1946; Mitchell and Linder, 1950). Staniforth and Loomis (1949) have recorded that the addition of surface-active agents, apart from their effect on retention, may also increase the area of spray contact and therefore the degree of penetration. These latter workers also noted that non-ionic and ionic surface agents differed in their wettability properties on corn and soybean. The rate of retention of sprays in determining selective toxicity of certain herbicidal materials has been reviewed in an excellent manner by Blackman (1950).

EXPERIMENTATION

Influence of Carrier on Inhibitory Effects of 2,4–D on Soybean

Effect of Pubescence: In order to study the influence of pubescence on the inhibitory effectiveness of 2,4–D aqueous sprays, with and without Carbowax, three types of soybean having different pubescent character were treated in a greenhouse experiment. Seed[5] of a pubescent type (T–122), a largely glabrous type (T–145) and a dominant glabrous type (T–151 Ia.) were planted in ½-gallon glazed pots on January 28, 1949. Fifteen days later pots containing two plants each were treated singly in a cylindrical chamber (0.1 sq. yd.), using a deVilbiss atomizer. Air pressure was held constant for all sprayings by a regulator manometrically controlled. Eight pots made up each treatment.

One hundred, 250, and 500 p.p.m. of the 2,4–D acid in wholly aqueous solution and in 0.5 per cent Carbowax 1500 aqueous solution were applied at a volume rate of 10 ml. per sq. yd., equivalent to 1.0, 2.5, and 5.0 mg. of 2,4–D per sq. yd., respectively. The inhibition of plants treated with 2,4–D in the Carbowax 1500 solution was noticeably greater for all three soybean types than resulted from the same levels of 2,4–D in the wholly aqueous treatments. Twenty

[5]Kindly furnished by the Iowa Agricultural Experiment Station, Ames, Iowa.

days after treatment, the plants were harvested; green weights were taken of the plant portion above the first trifoliolate leaf. These data are summarized in table 1.

From a study of the analysis of variance of the yield data obtained in this experiment (table 2), it was obvious that the 2,4–D in 0.5 per cent Carbowax 1500 spray was more inhibitory to all three varieties of soybean than the wholly aqueous sprays of the growth-regulator. The question arose as to whether or not this difference was attributable to increased adherence of the spray caused by the Carbowax. Accordingly, another experiment was made to determine the actual amounts of spray retained by glabrous and pubescent soybeans.

Spray Retention by Pubescent and Glabrous Soybean: On February 16, 1949, glabrous (T–145 Ia.) and pubescent (T–122) soybean plants selected for uniformity were cut off above the soil level, weighed rapidly on a Roller-Smith balance to the nearest mg., and then sprayed and reweighed. This operation was carried out in a cool, damp room in which determinations revealed little transpiration was occurring. The severed plants were supported during spraying in an upright position by placing the stem in a glass tube held

Table 1. Inhibitory effect of 2,4–D sprays on soybean plants differing in pubescence. Figures represent mean green weight (g.) per replicate (2 plants).

Mg. 2,4-D per sq. yd.	Aqueous	0.5% Carbowax 1500
	Pubescent (T-122)	
0	1.50	2.60
1.0	1.76	1.01
2.5	0.87	0.42
5.0	0.27	0.16
	Largely glabrous (T-145)	
0	1.41	1.36
1.0	1.20	0.69
2.5	0.70	0.38
5.0	0.22	0.09
	Glabrous (T-151 Ia.)	
0	2.44	1.62
1.0	1.46	1.00
2.5	1.27	0.77
5.0	0.46	0.47

Table 2. Analysis of variance for data in table 1.

Source	d.f.	Sum of squares	Mean square	F
Carrier (C)	1	2.79	2.79	39.85**
Rates (R)	3	61.72	20.57	293.85**
Plant type (P)	2	6.71	3.35	47.85**
C × R	3	3.29	1.09	15.57**
C × P	2	1.01	0.50	7.14**
R × P	6	2.76	0.46	6.57**
R × P × C	6	6.63	1.10	15.71**
Replicates	7	0.93	0.13	1.85
Error	161	11.38	0.07	——
Total	191	97.22	——	——

**Significant at the 0.01 level of probability.

by a large rubber stopper. The plants were handled with extreme care after spraying to prevent the spray droplets from running off before being weighed. The time elapsing between cutting the stem and the last weighing did not exceed two minutes. The spray technique was identical to that described previously. Eight plants made up each treatment.

The mean amounts of spray retained by pubescent soybean per gram of plant (green weight) were 0.037 and 0.030 g. for the Carbowax and wholly aqueous treatments, respectively; the glabrous plants retained 0.019 and 0.014 g. of the Carbowax and aqueous sprays, respectively. These data indicate on an average basis that compared with water, there was about 23 and 36 per cent more spray retained by the pubescent and glabrous plants, respectively, when Carbowax was employed.

The data on the pubescent soybean (T–122) and glabrous soybean (T–145 Ia.) from the above experiment were used to determine how much of the increased inhibition occurring in that experiment from the use of Carbowax could be accounted for by the increased adherence of the spray.[6] The totals of weights of two plants in eight replicates were converted to logarithms (coded by a factor of 10) in order to straighten the dosage-response curve. A straight line was computed by Least Squares methods for the water treatments and another for the Carbowax treatments. These two lines for each variety are the solid and long dashed lines in figures 1 and 2.

The method followed in making use of the information on the increased adherence caused by the Carbowax 1500 may be illustrated by this line of reasoning: If, for example, 100 p.p.m. of 2,4–D were sprayed in 0.5 per cent Carbowax 1500 about 20 per cent more agent would adhere to the plant than if the agent were sprayed in wholly aqueous solution. This might be thought of as meaning that 100 p.p.m. of the agent in the Carbowax was the equivalent of 120 p.p.m. of the agent in water. The response of the plants to 120 p.p.m. was determined from the "water line" calculated in figures 1 and 2. This gave a value (green weight) which could be expected to result from the use of 100 p.p.m. in the Carbowax 1500 carrier. This was done for successive doses and the resulting values were plotted to form the "expected" shown in the short-dashed lines in figures 1 and 2.

Statistical tests showed that the difference (on the order of 0.5 g. per plant) between the long-dashed and short-dashed lines was not significant for either variety. Accordingly, the increased inhibition of soybeans treated with 2,4–D in 0.5 per cent Carbowax 1500 over that of plants treated with the agent in a wholly aqueous carrier could be accounted for on the basis of increased adherence of the spray caused by Carbowax 1500.

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[6]Acknowledgment is made to Dr. C. J. Maloney and Mr. John Haynes of the Statistical Branch at Camp Detrick, Maryland, for making these computations.

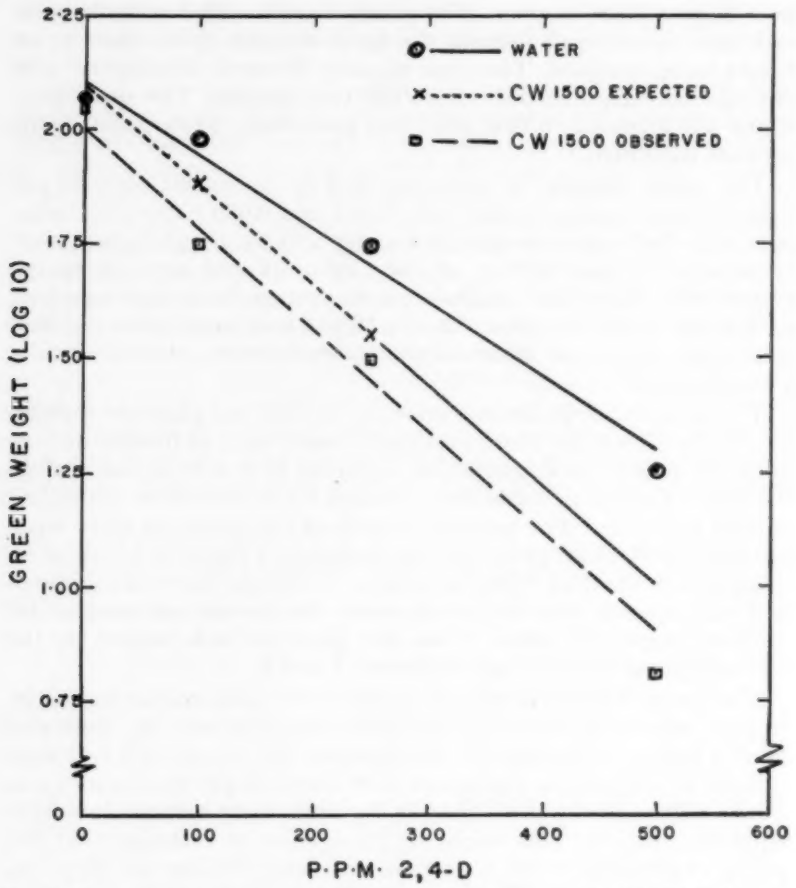

FIG. 1. Dosage-response curves for glabrous soybeans treated with 2,4-D in two carriers.

Effect of Leaf Angle and Leaf Pubescence on Retention of Sprays

The preliminary data in the preceding section indicated there may be marked differences in the amount of spray retained by pubescent and glabrous soybean plants.

Further to study spray retention by soybean plants, several other experiments were conducted in which the amount of spray adhering to the leaves of the plants was determined colorimetrically.

The general procedure is illustrated by that followed in one representative experiment. A standard density curve was established for Pontacyl Light Red BL dye aqueous solution, using a Klett-Summerson photoelectric colorimeter fitted with a No. 54 green filter. Tests revealed that the addition of 0.5 per cent Carbowax 1500 to water had no influence on the colorimeter readings.

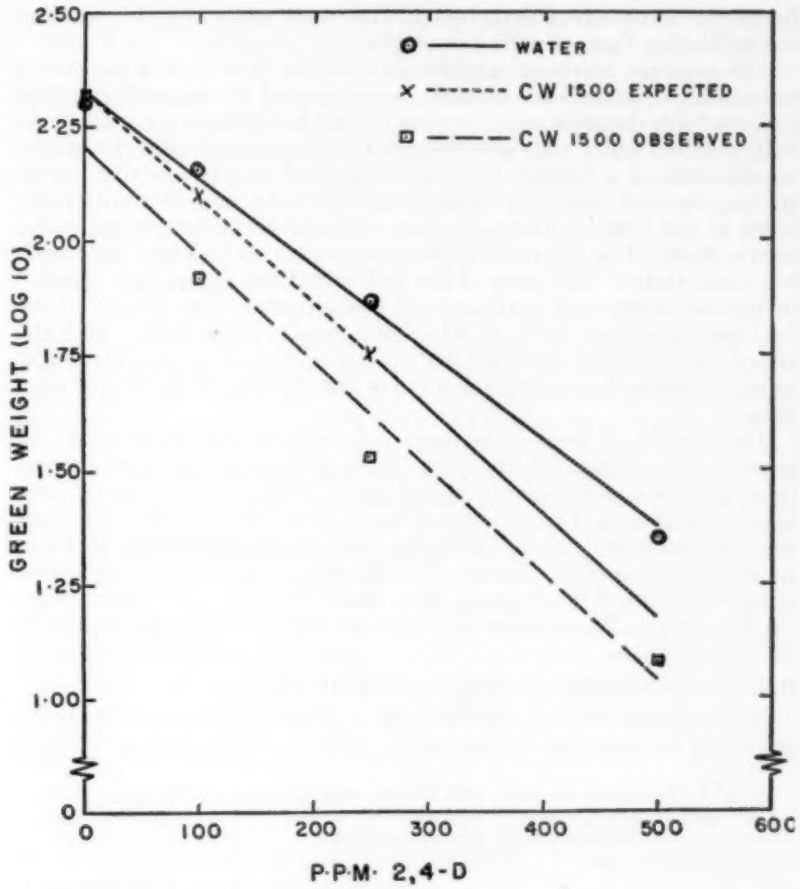

FIG. 2. Dosage-response curves for pubescent soybeans treated with 2,4-D in two carriers.

The stem of plants to be treated was severed just above the primary leaves and the potted plant was placed in the center of a cylindrical spray chamber, 0.1 sq. yd. in cross-sectional area. Prior to treatment, the deVilbiss atomizer used in spraying was secured firmly at the proper height to produce a cone of spray 0.1 sq. yd. in area on the floor of the spray chamber. Pressure on the sprayer was maintained manometrically at a constant pressure for all the treatments. As appropriate, the primary leafblades of the detopped plants were held horizontal (90°) or downward at 45° angles by a clamp which supported the petioles. The plants were sprayed singly with one ml. of a wholly aqueous or 0.5 per cent Carbowax 1500 aqueous solution, both containing 0.95 per cent of the Pontacyl dye. By supporting the leaves by their petioles, their resiliency was not altered as was

found to occur when detached blades were supported by wooden blocks having faces of different angles.

The primary leaves on a glabrous soybean, Var. T–145 Ia., and a pubescent soybean, Var. Lincoln, were treated in sextuplicate. The collected dye droplets were washed off the leaf blades quantitatively with distilled water after severing the petioles, and placing the blades on the wall of a funnel. Care was exercised to prevent shaking or jarring the leaf blades in cutting their petioles and in transferring them to the funnel. The rinse was collected in 50 or 100 ml. volumetric flasks. The identity of the primary leaves was kept and each was photostated. The areas of the individual leaves were determined by measuring the leaf outlines with a planimeter. The density of the dye was measured with a Klett-Summerson colorimeter and the actual ml. of liquid retained per sq. cm. of leaf area was calculated, using a standard concentration curve for the dye and the leaf area data.

The results of one experiment are summarized in table 3. An analysis of variance for the data (table 4) showed that spray retention differences attributable to leaf type, carrier, and leaf angle were highly significant. The pubescent leaves retained more droplets than the glabrous leaves. More Carbowax 1500 spray than wholly aqueous spray was retained by leaves of both types. Leaves in a horizontal position retained more spray than those held at a 45° angle from the horizontal. Three other greenhouse experiments gave essentially the same results.

Behavior of Droplets Impinging on Leaf Surfaces

In the course of studying the influence of Carbowax 1500 on the retention of aqueous sprays by glabrous and pubescent soybean

Table 3. Retention of water and 0.5 per cent Carbowax 1500 spray by the primary leaves of pubescent and glabrous soybeans. Figures represent mean mg. liquid retained per sq. cm. leaf surface.

Carrier	Leaf angle	Leaf type	
		Pubescent	Glabrous
Water	45°	0.660	0.409
Water	90°	1.186	1.071
Carbowax	45°	0.768	0.656
Carbowax	90°	1.618	1.432

Table 4. Analysis of variance for data in table 3.

Source	d.f.	Sum of squares	Mean square	F.
Leaf type (T)	1	0.330,340	0.330,340	7.85**
Leaf angle (A)	1	5.940,354	5.940,354	141.24**
Carrier (C)	1	0.987,854	0.987,854	23.49**
T × A	1	0.002,760	0.002,760	0.07
A × C	1	0.142,572	0.142,572	3.39
T × C	1	0.003,468	0.003,468	0.08
Replicates	5	0.109,564	0.021,913	0.52
Error	36	1.514,148	0.042,060	——
Total	47	9.031,060	——	——

**Significant at the 0.01 level of probability.

leaves, it was noticed that the wholly aqueous droplets frequently bounced from the leaves of the soybeans irrespective of whether the leaves were pubescent or glabrous. Further to study the behavior of droplets impinging on leaves, a series of experiments were made to observe individual droplets of various solutions after striking leaves of different species. A glass droplet-sizer (Ennis and James, 1950) which produces droplets singly and rapidly, was used in making the treatments. Droplets 0.5–0.7 mm. diameter were allowed to strike leaves of the various species held in a horizontal position. Some high-speed motion pictures were taken in order to study the individual droplet behavior.

Wholly Aqueous Droplets: There was a marked difference in the retention of aqueous droplets by the leaves of the various species studied. Aqueous droplets bounced off the leaves of many species while they were retained by the leaves of others (tables 5, 6, 7). The droplets sometimes adhered to the lower leaf surface of some species, but were repelled by the upper surface, e.g., Ladino clover and peanut. The petioles of lespedeza and peanut leaves and the veins of the leaves of soybean and Johnson grass retained aqueous droplets impinging on them, whereas the lamina of the blades repelled the droplets. Droplets bouncing from the lamina of the leaf blades of certain plants adhered frequently to the margin of the blades (tables 5, 6). Aqueous droplets striking the leaves of some plants broke up into many minor droplets (table 5). On tobacco and coleus, the water drops formed a circle of numerous satellite droplets.

Effect of Surface-active Substances: Aqueous droplets containing certain surface-active agents behaved differently from wholly aqueous ones upon impinging on the surface of leaves of some species. For example, aqueous droplets containing 1 per cent Tergitol 7 were

Table 5. Behavior of droplets of different solutions impinging upon the upper surfaces of leaves of certain greenhouse-grown plants. Figures represent average number of minor droplets produced by larger drops (ca. 0.6 mm. diameter) upon striking the leaves.

Plant	Wholly aqueous		1% Tween 20		1% Tergitol 7		5% oil-emulsion	
	Droplet retention	Minor droplets formed	Droplet retention	Minor droplets formed	Droplet retention	Minor droplets formed	Droplet retention	Minor droplets formed
Kidney bean	X	5.9	—	—	X	3.1	X	3.0
Peanut	XXX	—	XX	†	X	1.0	X	2.2
Coleus	X	11.5	X	6.3	X	1.6	X	3.8
Dandelion	X	6.2	X	2.3	X	1.3	X	1.7
Cabbage	XXX	—	XX	†	X	1.7	XX	3.0
Cabbage[1]	XX	—	X	—	X	—	X	—
Swiss Chard	X	2.8	X	2.0	X	1.0	X	1.0
Mullein	X	2.2	X	1.8	X	1.0	X	1.0
Tobacco	X	11.9	X	4.6	X	2.5	X	3.6
Sugar Beet	X	2.4	X	2.8	X	1.0	X	1.0
I. Potato	X	9.2	X	5.0	X	1.3	X	1.6
Oat	XXX	—	XX	†	X	1.0	XX	†
Sweet Potato	X	1.5	X	1.0	X	1.0	X	1.0

[1]Bloom removed.
X Droplets retained.
XX Droplets mostly retained, but some bounced off.
XXX Essentially all droplets repelled.
†Minor droplets produced but could not be identified with major drop due to bouncing.

Table 6. **Behavior of droplets of different aqueous preparations of 2,4–D impinging upon the upper and lower surfaces of the lamina of leaf blades of different plants. All the 2,4–D preparations contained 0.5 per cent of the acid equivalent and 0.1 per cent Safranin O dye.**

Species	Esteron 44[1]		Amine 2,4-D[1]		Amine 2,4-D[2]		Wholly Water		Na 2,4-D[2]		Morpholine 2,4-D[2]	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Dallis Grass	4	4	5†	5†	4	4	5†	5†	5	5	5†	5†
Corn	4	4	5	5	4	4	5†	5†	5	5	5†	5†
Oat	5	4	5	5	5	5	5†	5†	5	5	5	5
Peanut	5	2	5	2	4	2	5†	2†	5	2	5	2
Dock	1	1	1	1	1	1	1	1	1	1	1	1
Snapbean	2‡	2‡	2‡	2‡	2‡	2‡	2‡	2‡	2‡	2‡	2‡	2‡
Sida spp	1	2	1	2	1	2	1	2	1	2	1	2
Soybean (glabrous)	4	4	3	4	3	4	4†	4†	3	3	3	4
Soybean (pubescent)	3	3	2	3	4†	4†	4†	3†	3	3	3	3
Lespedeza	5	5	5	5	5	5	5†	5†	5	5	5	5
Ladino clover	5	1	5	1	5	1	5†	1†	5	1†	5	1
Cotton	1	1	1	1	1	1	1	1	1	1	1	1
Crimson clover	4	3	4	3	4	3	4‡	4†	4	2‡	–	–
Johnson Grass	4	4	5	4	5	4	3†	4†	5	5	–	–

[1]A formulated product supplied by the Dow Chemical Co., Midland, Michigan.
[2]A formulated product supplied by the E. I. du Pont de Nemours & Co., Wilmington, Delaware.
[3]Technical grade.
†Some droplets adhered to leaf veins, petioles or margins.
‡Several minor droplets formed.
1. All droplets retained, spreading.
2. All droplets retained, little spreading.
3. Droplets mostly retained, some bounced off.
4. Droplets mostly repelled, some retained.
5. Essentially all droplets repelled.

retained by the leaves of all species tested (tables 5, 7), and few minor droplets were produced. The inclusion of other surface-active substances in water caused greater retention of droplets than occurred without the addition of the materials. Depending upon the particular surfactant added, the droplets impinging on the leaves of certain species, such as the common cereals, cabbage, and Ladino clover, varied in their behavior from essentially no retention to complete retention (tables 5, 7).

Non-aqueous and Herbicidal Formulations: Droplets of oil and of the butyl ester of 2,4–D (tech.) were retained by the leaves of all species studied. Various forms of 2,4–D and commercial preparations of 2,4–D prepared as 0.5 per cent aqueous solutions or emulsions behaved differently when droplets impinged on the leaves of different plants (table 6). Species which retained wholly aqueous droplets likewise retained droplets of all the 2,4–D formulations tested. Species difficult to wet with water, such as certain grasses, corn, oat and lespedeza, repelled largely the droplets of 2,4–D preparations. Notwithstanding, the different 2,4–D formulations possessed varying wettability characteristics. For example, Dallis grass, oat and corn leaves repelled essentially all aqueous droplets containing 0.5 per cent technical grade of the sodium and morpholine salts of 2,4–D whereas droplets of the same concentration of 2,4–D prepared from certain commercial formulations were retained to some degree by the leaves.

Table 7. Behavior of droplets of different aqueous solutions containing different surface-active agents upon impinging on the upper and lower surfaces of leaves of different plants. All preparations contained 0.1 per cent Safranin O dye to facilitate observations.

Species	Wholly water		1% Santomerse D		1% Tergitol 7		1% Tween 20		1% Vatsol K		1% du Pont Sp. & St.		1% Tide	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Dallis Grass	5*	5*	2**	2**	1	1	3	3	1	1	4	3	3	3
Corn	5*	5*	2**	2**	1	1	2**	2	1	1	3	3	3	3
Oat	5*	5*	1	1	1	1	3	3	1	1	3	3	4	4
Peanut	5*	2*	1	1	1	1	1	1	1	1	2	1	3	2
Dock	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Snap bean	2**	2**	1	2*	2**	2**	2**	2**	2**	2**	2**	1	2**	2**
Sida spp.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Soy bean (glabrous)	4*	4**	1	2**	1	1	1*	2**	1	1	1	2**	3*	3*
Soy bean (pubescent)	4*	3*	2**	2**	1	1	2	2**	1	1	2**	2**	2	3
Lespedza	5*	5*	2	2	1	1	3	3	1	1	3	4	4	4
Ladino clover	5*	1*	2	1	1	1	2	1	1	1	4	1	5*	1
Cotton	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Crimson Clover	4**	4*	2**	2**	1	1	3**	3**	1	1	4**	3**	4	4
Nut grass	1	1	1	1	1	1	1	1	–	–	–	–	–	–
Johnson Grass	3*	4*	1	2**	1	1	1	2	1	1	1	3	1	3
Trumpet Creeper	1	1	–	–	–	–	1	1	–	–	–	–	–	–
Cypress Weed	1	1	–	–	–	–	1	1	–	–	–	–	–	–
Bitter Weed	1	1	–	–	–	–	1	1	–	–	–	–	–	–
Bermuda Grass	4	4	2	1	1	1	2	2	1	1	1	1	3	3
Horse Nettle	1	1	–	–	–	–	1	1	–	–	–	–	–	–
Crabgrass	4	4	2	2	1	1	2	2	1	1	2	3	3	3
Honeysuckle	1	4	1	2**	1	1	1	1	1	1	1	1	1	3

1. All droplets retained, spreading.
2. All droplets retained, little spreading.
3. Droplets mostly retained, some bounced off.
4. Droplets mostly repelled, some retained.
5. Essentially all droplets repelled.

*Some droplets adhered to leaf veins. petioles or margins.
**Several minor droplets formed.

Effect of Waxy Layer (Bloom): The waxy layer, bloom, was removed or disturbed on the leaves of some species by rubbing the surface lightly with the finger. By removing the waxy layer from the leaves of all the plants which otherwise repelled the droplets, complete droplet retention occurred.

Because the waxy layer on the leaves of plant species appeared to be the most important character involved in repelling droplets, a limited study was made in an attempt to determine the nature of this layer. Glass slides were coated with a large variety of substances and the behavior of aqueous droplets impinging on these slides was observed. No material used caused the droplets to bounce from the slides. The contact angles of droplets impinging on slides coated with paraffin, tissue matte, and beeswax were larger than those for the other materials tested, however, all droplets were retained on the slides.

The waxy layer was removed from cabbage leaves by washing them with ether and then the dissolved material was deposited on glass slides and also on thin cellophane. The deposition did not repel aqueous droplets. Apparently the physical properties of the natural waxes on the leaves of cabbage and possibly the resiliency of the leaves are important factors in repelling aqueous droplets.

DISCUSSION

Foliage sprays of herbicidal materials, applied uniformly over a mixed population of certain crop plants and weeds may affect differently the various species depending upon the relative amount of the spray retained by the leaves of certain of the plants. Retention of the spray is dependent upon the characteristics of the spray and the species involved. Surface tension of the spray droplets, droplet velocity, and droplet size are important factors which can be altered sometimes to accomplish differential wetting. The results of this study demonstrated important differences between plant species with regard to retention of wholly aqueous droplets and aqueous droplets containing certain surface-active agents. As reported by Blackman (1950) wettability of leaves is determined by a combination of the physical and chemical nature of the leaf surface and the physical properties of the spray. Our studies showed that by removing or disturbing the waxy surface of leaves that normally repel wholly aqueous droplets, the leaves will retain water droplets readily. Also, the repellent character of leaves can be overcome by inclusion into the spray solution of certain surface-active substances. Commercially available surface-active materials added to water vary in their wettability properties. Accordingly, some care in the selection of agents to alter the surface tension of sprays is indicated. If it is considered important to use a surface-active agent in the spray solution it should be one to accomplish the desired amount of spray retention by the undesirable species with little wetting of the crop plants.

Additionally, the gross external morphology of the plant is an

important factor in the retention of sprays. The angle and orientation of leaves influence the number of spray droplets remaining on them. Soybean leaves in a horizontal position intercept and retain a greater quantity of spray than leaves pointed at a 45° angle. No doubt the lack of retention of wholly aqueous sprays by many of the cereals and grasses under field conditions is attributable in part to their erect leaves. Sprays applied under high pressures may change the normal angle of the leaves of plants to such an extent that the droplets are repelled.

Certain herbicidal sprays applied for non-selective killing of plants may be improved frequently by the addition of some surface-active agents. The materials increase the retention of sprays by the foliage of many species and may also enhance penetration or absorption of the herbicide.

Sprays applied for selective killing are least hazardous to the crops where the spray droplets possess high surface tension. For example, our data show that aqueous droplets containing herbicidal concentrations of technical grades of the sodium and morpholine salts of 2,4–D are repelled by such species as corn, oat, and Dallis grass whereas droplets of certain formulated ester and amine forms of 2,4–D are retained to some extent. Weed species easily wet with aqueous sprays, such as dock and Sida spp., might be controlled in some crops, e.g., oats, with the greatest margin of safety to the crop by using herbicidal preparations comparable to the forementioned sodium and morpholine salts of 2,4–D. There may be many other dicotyledonous weeds which could be controlled selectively with less hazard if sprays of higher surface tension than many of the commercially formulated 2,4–D products were employed. Many instances of greater injury to cereals from the application of certain ester formulations as compared to aqueous sprays of the salts of 2,4–D may be attributable to a greater droplet retention by the crop plant leaves than results from the latter sprays of higher surface tension.

SUMMARY

1. Studies on the influence of pubescence, leaf angle, surface-active agents, and other factors on the retention of sprays by certain plants and on the behavior of droplets impinging on leaves of different species are recorded.

2. Pubescent soybean leaves retained more wholly aqueous and 0.5 per cent Carbowax 1500 spray than glabrous soybean leaves. More Carbowax 1500 spray than wholly aqueous spray was retained by both glabrous and pubescent soybean leaves. Leaves in a horizontal position retained more spray than those at an angle of 45° from the horizontal.

3. The increased inhibition of soybean plants treated with 2,4–D in a 0.5 per cent Carbowax 1500 aqueous solution over that of 2,4–D applied in a wholly aqueous spray was attributable to a greater retention by the plants of the former.

4. Uniform size droplets of water solutions containing certain

surface-active agents and aqueous preparations of different forms of 2,4–D varied greatly in their behavior upon impinging on the leaves of different plants. Retention of droplets of different liquids varied from essentially none to complete retention by certain species. Some species retained wholly aqueous droplets as readily as those containing surface-active agents. The upper and lower surfaces of leaves differed in their capacity to retain droplets.

5. Surface-active agents vary greatly in their wetting characteristics. It is suggested that the selectivity of herbicidal sprays may be improved by exercising care in choosing the form of herbicide and carrier to use.

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BOOK NOTES

By CAROL H. WOODWARD

ILLUSTRATED GUIDE TO TREES AND SHRUBS. Arthur Harmount Graves. 240 pages. Published by the author at Wallingford, Conn. 1952. $4.

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Easy-to-use keys to the vegetative characters of 2,286 varieties and species of woody plants, both wild and cultivated.

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ARRANGING FLOWERS FROM THE ROADSIDE, FIELDS AND WOODS. Amelia Leavitt Hill. 136 pages. Crowell. 1952. $3.85.

Artistic value of wild flowers of the United States, from coast to coast — an

object lesson in conservation for those who are wont to destroy all vegetation on a spraying job.

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The author's own choice of the 745 best trees for horticultural use in the United States and Canada, with many classified lists and a long supplementary list of trees which he considers of secondary importance.

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for October, November, and December, 1951

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Prepared By

Division of Weed Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture

This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Division of Weed Investigations does not assume responsibility for the subject matter cited.

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